THE METALLOGENIC EPOCHS OF TASMANIA

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Introduction

I. PREVIOUS LITERATURE.

There has been no previous attempt to deal comprehensively with the genetic and chronologic classification of the ore deposits of Tasmania. From time to time, however, during the last twenty years various officers of the Geological Survey of Tasmania have drawn attention to certain conclusions as to age and genesis which seemed justifiable from the evidence presented by the ore deposits of restricted districts.

Thus G.A.Waller twenty years ago drew attention to the genetic relationship between the tin deposits and the common granite of Tasmania on the one hand and the nickel deposits and the congeners of the granite, serpentine and gabbro on the other. In the years following the late W.H.Twelvetrees and Waller tentatively assigned to a large number of ore deposits a genetic connection with the granite. In the case of many deposits, however, such as, for example, the Read-Rosebery zinc-lead sulphide ore-bodies, considerable doubt as to genesis and age arose because of inability to definitely determine the true mode of origin of the adjacent keratophyre - whether intrusive or extrusive. Likewise as W.H.Twelvetrees developed the conception of the separate entity of the porphyroid igneous suite with a typical granite as a well developed facies, the possibility of a genetic relationship between some of our ore deposits and this granite became apparent, but no progress in the development of this idea was made until 1913 and onwards.

In the year 1910 the systematic investigation of the Zeehan silver-lead field by W.H.Twelvetrees and L.Keith Ward, which really carried onwards to a further stage the most valuable pioneer work of G.A.Waller, gave an opportunity of applying some of the principles controlling the deposition of ore deposits which had been enunciated by eminent economic geologists of America and Europe. The result was the interpretation of genesis presented in Bulletin No.8 of the Geological Survey of Tasmania. Such interpretation involves the origin of all of the deposits from the Devonian granite the various types of deposits being determined by zonal precipitation in three main zones - (1) metamorphic zone; (2) pyritic-galena zone; and (3) sideritic-galena zone.

In the year 1911 the late W.H.Twelvetrees applied the conception of metallogenic epochs and provinces to the Scamander field and presented a short statement as to the metallogenic epochs of Tasmania in Geological Survey of Tasmania Bulletin No.9. In this publication attention was drawn to the coincidence of the gold-quartz lodes and the sub-acid (granodiorite) facies of the Devonian granite.

At the beginning of the year 1912 L.Keith Ward after his studies of the Farrell, Dundas, Zeehan and Balfour districts of the preceding four years presented several papers before the Australian Association for the Advancement of Science, two of which were entitled "An Investigation of the Relationship between the Ore-bodies of the Heemskirk-Comstock-Zeehan Region and the Associated Igneous Rock" and "The Heemskirk Massif - its Structure and Relationships".

In these papers Ward developed the conception of a Devonian age for the ore deposits of the whole of the West Coast region assigning their origin to the Devonian magma which, containing the material for both the granite and its associates and the ore deposits, was irrupted along lines of crustal weakness running in a general north-easterly direction and not as a large all-underlying batholith. He regarded the Heemskirk massif as chonolithic in structure, that is possessing a definite bottom, and that the expulsion of the ore-bearing solutions was continuous and ultimately had a sudden cessation due to the sealing up of the connection between the chonolith and its magmatic reservoir. Zonal precipitation according to temperature-pressure conditions was held as explaining the various types of ore deposits. The possible genetic significance of the porphyroid granite was ignored by Ward, and the metallogenic problem of the West Coast Range was not discussed but all of the ore deposits of that important and complex belt were indiscriminately ~~lumped~~ placed into the Devonian metallogenic epoch.

In 1913 the writer studied the metallogenic problem in the Jukes-Darwin district especially from the viewpoint of the genetic significance of the porphyroid granite. The discussion of that problem as it appeared at that time is contained in Geological Survey of Tasmania Bulletin No.16 which shows that the porphyroid granite has been definitely responsible for certain of the ore deposits of that district.

From that date onwards no publication contains any further contribution to the literature on the general question of metallogenic epochs of Tasmania although continuous additions to our knowledge of the geology and ore deposits of the various mineral districts have been made by officers of the Geological Survey of Tasmania. Thus the writer in the Read-Rosebery district definitely established the effusive origin of the keratophyre thus eliminating a troublesome complication in the problem of metallogenesis. This investigation is described in Geological Survey of Tasmania bulletins 19 and 23. The writer's investigations have included all of the mineral districts and practically the whole of the explored area of Tasmania, in particular containing a detailed study of the geology and ore deposits of Mt.Lyell, the results of this latter work, however, not having yet been prepared for publication.

II. ABSTRACT.

The study of the metallogenic problem in Tasmania offers most exceptional opportunities for the investigation of the general principles controlling the formation of ore deposits, because there are developed in this State a wonderful variety of deposits concentrated within an unusually small area. It will be seen in the subsequent pages that as a result of the research described therein not only has some approach to finality in the solution of the Tasmanian metallogenic problem been attained, but that some new light has been thrown on the mechanism of the derivation of ore-bearing solutions from igneous magmas in general.

The method of approach to the problem of metallogenesis used in this investigation is that of the geologic relationships of the ore deposits - their relation to the geologic structure and history of the region in which they occur. All phases of geologic knowledge are applied to the problem - stratigraphic, tectonic and plutonic geology all being called upon to contribute evidence for the determination of the age and genesis of the ore deposits.

The work is accordingly presented in two parts - Part I being the Geologic Background and Part II the Statement of Metallogenesis. The essential geologic facts are given in Part I in order to supply the foundation for the detailed examination of the ore deposits in Part II.

Part I.

Chapter III deals with such phases of the physiography of Tasmania as are essential to a proper understanding of the descriptive matter in the subsequent pages.

Chapter IV deals with the stratigraphic and petrologic geology of Tasmania, particular attention being paid to all rock series older than Permo-Carboniferous.

Chapter V presents a comprehensive survey of the tectonics of Tasmania and this is then used as the means of attacking the problem of plutonic geology. Approached in this way the genetics and structure of the igneous rocks become apparent. In this way the character and origin of the Porphyroid Igneous Complex are elucidated and described in some detail, the final conclusions in regard to this igneous series being based on the conception of the Petrogenic Cycle. There then follows a thorough investigation of the Epi-Silurian plutonics on the same lines and the conception is evolved of the existence of one large composite Tasmanian Epi-Silurian Batholith consisting of the North-Eastern batholith and the West Coast Batholith. The tectonic factors which have determined the configuration of the batholithic roof are indicated and the position of the pronounced cupolas determined. It is pointed out that the Epi-Silurian orogenic compression was characterised by a more pronounced vertical component than either of the preceding orogenic revolutions.

Part II.

The method adopted in approaching the problem of metallogenesis is to initiate the investigation of the metallogeographic provinces of Tasmania. These are dealt with in Chapter VI.

Chapter VII advances the study by considering the relationship of the metallogeographic provinces to outcrops of plutonic

rocks and areas of intense orogenic movement.

The relationship to the tectonic lines is further considered in Chapter VIII by comparing them with the orientation of the fissure lodes of typical areas.

Having exhausted the conclusions deducible from the above considerations the determination of the geologic age of the ore deposits is then effected by utilising systematically the age of the rock repositories of the various types of deposits indicated in detail in Table II and explained in Chapter IX.

In Chapter X this age determination is thus finalised for a large number of the ore deposits on direct geologic evidence and in Chapter XI this number is increased by basing further age determination on mineralogic analogy to those already fixed as to age.

This age determination systematically effected for the first time results in the conception of two main Metallogenic Epochs - (1) the Epi-Silurian and (2) the Epi-Cambro-Ordovician. There are also two epochs of much less importance.- the Cretaceous and Tertiary Metallogenic Epochs. Without exception these four Metallogenic Epochs coincide with epochs of pronounced igneous activity and the two major Metallogenic Epochs also are coincident with epochs and areas of very pronounced orogenic movement.

Chapter XII deals specifically and in detail with the Epi-Silurian Metallogenic Epoch. Its relationship to the metallogeographic provinces is indicated as a preliminary and there follows a detailed investigation of its relationship to the Epi-Silurian petrogenic period. It is shown that there was a Basic and an Acid Phase of the metallogenic epoch corresponding to the two main petrogenic phases. The Acid Phase is shown to be subject to important subdivisions and a definite genetic significance is shown to belong to the upwardly projecting supolas. It is shown that the distribution of the materials which formed the ore deposits, immediately prior to their emission from the magma, was determined by the configuration of the batholithic roof. There is developed the conception of the Cupola and Inter-Cupola Trough Horizons between which there has been a differential movement of the more mobile metallic constituents upwards into the former. The spatial arrangement of the ore deposits of either the Cupola or Inter-Cupola Trough Horizons is due to intermittent ejection of solutions from the magmatic reservoir, each stage being followed by a sealing up of the ejection channels and a subsequent opening of mostly new but parallel fissures through which were ejected the solutions of the following stage. This intermittent emission occurred at intervals during the progressive cooling of the magma and its differentiation but there is not sufficient evidence available to allow of the correlation of the various Metallogenic Stages with the progressive rock differentiates. Deposition in any Stage was determined by temperature and pressure conditions in the fissures and consequently as the magma cooled the zone of any temperature condition receded inwards towards the magma, thus causing lodes characterising markedly different temperature-pressure conditions to be deposited in close proximity to each other. Primary depth zoning within a lode system occurs only to a subordinate extent. The present distribution of the ore deposits of the Acid Phase of the Epi-Silurian Metallogenic Epoch, therefore, has been controlled by the intermittent ejection of solutions from the progressively cooling and differentiating magma accompanied by an inward migration of temperature - pressure conditions, rather than by a zonal precipitation from a continuously evolved solution.

The several stages of each Horizon are indicated and discussed at some length.

The Epi-Silurian Metallogenic Epoch is shown to give rise to deposits containing the metals, tin, tungsten, bismuth, copper, zinc, lead, silver, gold, iron, nickel, osmium, iridium, and arsenic.

In Chapter XIII the Epi-Cambro-Ordivician Metallogenic Epoch is dealt with and two Phases are again demonstrated, namely, the Basic and Acid Phases. The ore deposits of this epoch are shown not be as numerous or varied as those of the Epi-Silurian, being characterised by predominant iron and some copper. Their relationship to the Porphyroid Igneous Complex is fully discussed.

In Chapter XIV certain ore deposits are dealt with which have not resulted from direct magmatic emanations but have been formed by anamorphic processes during dynamic metamorphism.

Chapter XV includes a short discussion on the secondary alteration of the ore deposits.

Chapter XVI is presented in the form of a table and constitutes a genetic and chronologic classification of the ore deposits of Tasmania. The effect on the ore deposits of both minor and major regional variation of the metallic composition within the magma, is demonstrated and the nett conclusions of the preceding investigations and discussions are clearly stated.

The various tables and maps, plans and sections used to illustrate this work are indicated in the Table of Contents. There are ten plates and four tables.

PART I.

GEOLOGIC BACKGROUND.

III. - PHYSIOGRAPHY.

A. - GEOGRAPHICAL POSITION AND AREA.

Tasmania is a heart-shaped island lying to the south-east of Australia being distant therefrom 150 miles. It lies between $144^{\circ}39'$ and $148^{\circ}23'$ East Longitude, and between $40^{\circ}32'$ and $43^{\circ}39'$ South Latitude.

Its maximum width in an east-west direction is 195 miles and its greatest length in a north-south direction 180 miles. The width at the latitude of the centre of the island is 150 miles. The area is 26,215 square miles.

B. - TOPOGRAPHY.

THE DIABASE HIGHLANDS.

The dominant topographic feature is the central plateau. This topographic unit is situated in the centre of the island and has a width of 70 miles with a length of 50 miles. The northern, north-western and western portions of the plateau are the highest with peaks varying from 4500 feet to 5000 feet in height, the general level of 3500 feet in this portion falling in a south-easterly direction to 2700 feet with peaks of 3500 feet.

Separated from the north-eastern end of this plateau by the Midlands-Westbury Plain there is a rise to the Ben Lomond Massif which has an elevation similar to that of the Central Plateau with peaks 4000 to 5000 feet in height but is of comparatively small areal extent.

Connected with the Central Plateau by the Oatlands Saddle (1350 feet) are the East Coast Highlands which reach a maximum elevation of 3000 feet and which are separated from the Ben Lomond Massif by the valley of the South Esk River.

Separated from the Central Plateau by the valley of the River Derwent are the Wellington-Humboldt and Hartz Mountain Ridges with an elevation ranging from 4000 to 4500 feet.

The whole of the upland regions so far described constitute one geological unit, consisting in the southern and eastern portions of diabase in the upper portion with Trias-Jura and Permo-Carboniferous sediments on the flanks ~~and at the base~~.

~~Vide infra p.~~

~~Vide infra p.~~

Being thus constituted and because the occurrence of diabase is so characteristic this topographic feature can best be referred to as the "Diabase Highlands" and the writer herewith proposes this designation which will be used throughout this work.

The topographic units now to be described represent a far greater diversity in geologic structure than this as well as a greater complexity of topographic form.

THE SOUTH-WESTERN MOUNTAIN SYSTEM.

The South-West Mountain System extends from the Bathurst Range near Cox's Bight in the south to Frenchman's Cap and the Raglan Ranges in the north. It consists of a number of parallel mountain ranges which run in a general meridional direction. Their elevations range from 1000 feet to nearly 5000 feet They are composed wholly of rocks of Pre-Cambrian age (1) and constitute a rugged and precápitous region, the greater part of which is still unexplored.

THE WEST COAST RANGE.

The West Coast Range runs in a meridional direction from Mt.Darwin near Kelly Basin on Macquarie Harbour to Mt.Farrel which is due west of Cradle Mountain. The axis of the range is 20 miles from the sea-coast. It consists of a long ridge with peaks varying from 3000 to 4200 feet in height. The peaks from south to north are named as follow: Darwin, Jukes, Huxley, Owen, Lyell, Sedgwick, Geikie, Tyndal, Read, Murchison, Black and Farrel. (2) ~~Tee~~

The whole of the West Coast Range consists of members of the Porphyroid Igneous Complex (3) and the West Coast Range conglomerate series. (4)

THE DARWIN PENEPLAIN.

The western foothills of the West Coast Range, the western ranges of the South-Western Mountain System and the north-western edge of the Central Plateau merge into the topographic unit which the writer now proposes to designate as the Darwin Peneplain.

Integral portions of the Darwin Peneplain have been recognised and described by various investigators in separate localities.

The writer has formed the conception of one extensive piedmont peneplain extending in a roughly crescentic arc from Rocky Point on the south to the Middlesex district in the north. The name "Darwin Peneplain" is proposed to designate this topographic unit as its extent coincides approximately with that of the Darwin Electoral Division of Tasmania.

The surface of this peneplain has a gradual slope seawards ranging from 60 to 100 feet per mile and there is invariably a final rapid drop of from 200 to 400 feet immediately behind the

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(1) Vide infra p.10
(2) As the greater number of these names are those of well known geologists the range is sometimes termed "the Geologists'Range".
(3) Vide infra p.15
(4) Vide infra p.12

coast-line. Above this general surface rise numerous monadnocks which have a general elevation of from 2500 to 2700 feet above sea-level. These will be described below under the heading of "The West Coast Granitic Massifs".

The peneplain is now deeply dissected and can only be recognised by taking cognisance of the tops of the ridges and the few remaining portions of the original levelled surface. This new cycle of erosion is still in its youthful stage.

There is no geologic feature common to all parts of this topographic unit practically all geologic formations from Pre-Cambrian to Pleistocene being represented.

THE WEST COAST GRANITIC MASSIFS.

Rising from the general surface of the Darwin Peneplain to a height of from 2500 to 2700 feet above sea-level are the residual monadnocks known as Mt. Heemskirk, Parsons' Hood, Mt. Ramsay, Mt. Bischoff, Meredith Range, Magnet Range, Norfolk Range and Mt. Zeehan. With the exception of the two latter these massifs are composed either wholly of or have as their dominant component either granite or its congenors. Of the remaining two the Norfolk Range most probably has a granitic core (5) while Mt. Zeehan differs from all of these others in being composed wholly of West Coast Range conglomerate.

THE NORTH-EASTERN GRANITE MASSIFS.

The north-eastern portion of Tasmania extending from the north-eastern limit of the Ben Lomond Massif constitutes a topographic unit the general character of which is that of a much dissected upland area.

The dominating geologic feature of this topographic unit is the occurrence of granitic rocks which constitute the greater part of it.

THE MIDLAND-WESTBURY PLAIN.

Extending from Tunbridge towards Launceston and Westbury and bounded on the west and east by the Central Plateau and the Ben Lomond Massif respectively is a gently undulating region from 500 to 700 feet above sea-level. The greater part of this area is composed of Tertiary lacustrine deposits overlain in places by basalt of Tertiary age.

Tasmania is thus seen to be essentially a mountainous country, the mountain ranges and highlands being broken by a succession of deep gorges. The greater part of the island being still in the youthful stage of a cycle of erosion, deep steep-sided valleys are characteristic and this deeply dissected character of the surface makes exploration and access difficult. The greater part of the western portion of the island is covered with a thick impenetrable forest.

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(5) Vide infra p. 66

C. - CLIMATE.

From the climatic standpoint Tasmania may be divided into two portions - the Western District and the Eastern District. The former is characterised by an annual rainfall varying round 100 inches according to the height above sea-level, while the latter has a rainfall varying from 20 to 30 inches. The mean annual temperature is in the vicinity of 50°F.

Launceston has a mean annual temperature of 54·8°F. and an annual rainfall of 28 inches. Zeehan has a mean annual temperature of 51·5°F. and an annual rainfall of 98 inches.

The extreme East Coast is drier than Launceston while the more elevated portions of the West Coast are wetter than Zeehan. In the former case the rainfall is as low as 18 inches (Scamander), and in the latter case as high as 140 inches (Mt.Read). The mean annual temperature, however, while being slightly higher and lower respectively in these two localities does not depart by more than a few degrees from the mean of 50°F. The highest temperature which only very occasionally occurs is 102°F. in the shade while the coldest, which is also very infrequent, is 24°F.

Snow is uncommon in the southern, eastern, and northern parts of the State except on the higher portions of these areas, and then only in the winter months. On the Central Plateau, however, snow falls at any time of the year and for about four or five months the snowfall is considerable & remains unmelted up to about October. On the West Coast the snowfall is appreciable, but does not remain long, as it is usually dispersed by the north-westerly rains which quickly follow.

IV. - STRATIGRAPHICAL GEOLOGY AND PETROLOGY.

A. SEDIMENTARY ROCKS.

1. PRE-CAMBRIAN.

PROTEROZOIC.

The rocks referred to the Pre-Cambrian in Tasmania consist wholly of metamorphosed sediments. They now consist of schistose conglomerates, quartzites, quartz-schists, quartz-mica schists, argillaceous schists, micaceous schists and to a lesser extent graphitic schists and dolomitic limestones.

The Pre-Cambrian rocks of Tasmania have not been very closely studied and very little is known either of their stratigraphy or their structural geology. Their distribution, however, has been approximately determined and is shown in the accompanying geological map.[6] Their greatest development is in the South-Western Mountain System of which they are the predominating components.

L.K.Ward[7] has indicated the existence of two horizons in this sedimentary rock series separated by a marked unconformity. The upper horizon consists of white quartzite schists gently folded while the lower horizon consists of the more closely folded and, in places, highly crenulated and contorted quartz-schist and quartz-sericite schists. Associated with rocks possessing these latter characteristics there occur on the coast between Cape Sorell and Point Hibbs beds of dolomitic limestone partly marmorised.[8]

2. PALAEOZOIC.

(a). CAMBRIAN

The only occurrences of rocks definitely referrable to the Cambrian system are at Cardine Creek near Railton in the north and on the Humboldt Divide in the south. They are merely isolated outcrops, the relationship of which to other formations is obscure.

(b). CAMBRO-ORDOVICIAN

eehan Slates and andstones

Associated with the highly altered igneous rocks of the Porphyroid Igneous Complex[9] and interbedded with the effusive members thereof, there occur many varieties of sedimentary rocks. All of these rocks have lost much of their original character and now occur in the form of slates, quartzites, conglomerates, quartzitic, argillaceous, chloritic and calcite schists. Sufficient of their original structures, however, has been preserved to definitely establish their sedimentary origin. In the Zeehan field and extending therefrom to the Heemskirk field occur a contorted series of sandstones and graphitic slates. Their thickness has not been determined but they apparently underlie the Dundas Slates.[10]

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[6] Plate I
[7] ~~Loc. cit. pp. [illegible]~~ Ward L.K. Roy. Soc. Tas. 1909 pp 124-155
[8] Loftus Hills, Geol. Sur. Tas. Bull. 18 p 9
[9] Vide infra pp.
[10] Twelvetrees, W.H. & Ward, L.K. Geol. Surv. Tas. 8 pp. 35-37

(1). Dundas Slates.

The most widespread in distribution and persistent in lithological character of the rocks in this system are the Dundas slates. The rock-types of this sedimentary series have been fully described by L.K.Ward.(11) The most characteristic is a purple slate possessing distinct slaty cleavage which is often very highly developed and which is never absent. The cleavage is at all angles and relative orientations to the bedding planes. Variants from this type occur ranging from green or brown to greyish black in colour, from purely argillaceous to more siliceous in composition, and from extremely fissile to more massive beds showing a less perfectly developed cleavage. Occasional grits and conglomerates are interbedded with these slates.

The Dundas slates are typically developed in the Dundas district on the West Coast. They have been recognised and definitely correlated on lithological grounds by the late W.H. Twelvetrees in the Leven district in the north(12) and at Mts. Mueller and Humboldt in the south. On the same grounds the writer has recently concluded that the slates in the vicinity of Lynchford, occurring west of the rocks of the Porphyroid Igneous Complex of the Lyell district, belong to the same series. They are extensively developed in the Stanley River district and also in the North Pieman district. Thence they extend north-westwards towards the Arthur River occupying a considerable part of the surface in the Mt.Bischoff district, and north-eastwards towards the Leven River.

(2). Read-Rosebery Schists.

The Read-Rosebery schists constitute the next most important series of these Cambro-Ordovician sediments. They have been described by the writer who was the first to recognise their original sedimentary character.(13) The rock-types range from quartzitic, chloritic, argillaceous and calcite schists to what is really a schistose argillaceous limestone. They all possess a well defined schistosity which is characteristic and is quite independent of the original bedding planes. The typical Read-Rosebery schist is an argillaceous rock possessing a marked schistosity often showing the original bedding, and containing sporadically distributed blebs and rhombohedrons of calcite.

From this typical argillaceous schist there is a gradation in two directions. On the one hand a gradation occurs to quartzitic schists and chloritic schists by an increase in the amount of silica and chlorite respectively and a disappearance in both cases of the calcareous constituent. On the other hand by an increase in the percentage of lime and magnesia the type becomes a schistose calcareous rock composed of successive bands of calcite-dolomite crystalline aggregates and the normal argillaceous schist.

The stratigraphy of the Read-Rosebery schists and the Dundas slates has been worked out by the writer.(14) The latter are at least 5000 feet in thickness although this figure includes the interbedded volcanic breccia and tuffs. They have been shown to be older than the Read-Rosebery schists which they conformably underlie. The latter are 1200 feet in thickness, the argillaceous and calcareous horizon being 200 feet thick and located at about the middle of the series.

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(11) Ward, L.K., Geol.Sur.Tas. Bull.6 pp.32-34
(12) Ward, L.K., Loc. cit.
(13) Twelvetrees, W.H. Geol.Surv.Tas. Bull.5 pp.8-10
(14) Loftus Hills Geol. Surv. Tas. Bull 19 pp 11-26; + 18 pp. 13-30 + 38-42

Interbedded with the intrusive members of the porphyroid igneous rocks described below there occur frequent beds of undoubtedly true sediments generally finely bedded and almost invariably of argillaceous composition.

The age of these sedimentary series has not been definitely fixed on palaeontological evidence. Stratigraphical evidence, however, shows that they are younger than the Pre-Cambrian (15) (15a) and older than the base of the Silurian from which they are separated by a marked unconformity.

The Zeehan slates and sandstones, the Dundas slates and breccias and the Read-Rosebery schists are therefore of either Cambrian or Ordovician age. Since their relationship to the only undoubted Cambrian beds we have in Tasmania is uncertain they are provisionally classed as Cambro-Ordovician.

There are two other important series of sedimentary rocks which must be referred to the same combined period but which cannot be definitely correlated with the series already described. These are the Balfour slates and sandstones and the Mathinna slates and sandstones.

(3). Balfour Slates and Sandstones.

A large area in the Balfour district is ~~of~~ constituted of this series. They have been described by L.K.Ward (16) and consist of slates, sandstones, grits and occasional conglomerates. They differ from the Dundas slates series in that the slate members are dark grey to white and even green in colour and the fact that the slates and sandstones are in approximately equal amount. Their structural features and the degree of fissility of the slates are very similar to those of the Dundas slates. They resemble the latter also in being intruded by igneous rocks of the Porphyroid Igneous Complex, especially amphibolites.

(4). Mathinna Slates and Sandstones.

This series occurs throughout north-eastern Tasmania and has been intruded by the Devonian granite. It includes the oldest rocks of the Mathinna, Lefroy, Beaconsfield, Scamander, Victoria and Gladstone districts. The constituent rocks are slates sometimes slightly graphitic, sandstones and quartzites. The slates are of various colours resembling to a considerable degree the Dundas slates. The only justification for placing this series in the Cambro-Ordovician is the lithological and structural resemblance to both the Dundas slates and the Balfour slates and sandstones. They have so far proved quite unfossiliferous. Nevertheless the writer feel confident that subsequent investigations will confirm his opinion that their lithological and structural characters warrant their being regarded as portion of the Cambro-Ordovician sedimentaries.

(c). SILURIAN.

(1). West Coast Range Conglomerate Series. - This is a series of very coarse to fine grained conglomerates, grits, breccias, quartzites, shales and sandstones. They have been described by S.A.Waller (15) L.K.Ward, (17) the late W.H.Twelvetrees, (18) A.McIntosh Reid (19) and the

(15) Waller S.A. Report on Zeehan Field 1904
(15a) Loftus Hills Geol. Surv. Tas. Bull 16 pp 58-62
(16) Ward L.K. Geol. Surv. Tas. Bull 10 pp. 31-37
(17) " " " " " " 3 p 23 et seq.
(18) Twelvetrees W.H. Geol. Surv. Tas. Bull 14 p. 14 et seq.
(19) Reid A.M. " " " " 29 pp 24-28

writer.[20] Recently the writer has finalised his previous work by elucidating the details of the stratigraphical geology and tectonics of this series.

The typical conglomerate is white to pale pink in colour and is almost wholly siliceous.

At the base is a breccia which varies in thickness and is sometimes absent. Overlying the series and conformable thereto, and in fact forming part thereof is the Tubicolar sandstone which increases in thickness from south to north.

The total thickness, exclusive of the basal breccia and the tubicolar sandstone, is 1680 feet.

The West Coast Range Conglomerate series is restricted to portions of a belt extending from a line joining the Denison Range to Zeehan, north-eastwards through the West Coast Range to Mts. Claude and Roland and the Dial Range. It caps the greater part of the West Coast Range as well as many mountains along this belt.

(2). Limestone Series. - The predominant rock-type of this series is a dark blue limestone with which are associated some interbedded slates and quartzites. The series has been described by the late W.H.Twelvetrees and L.K.Ward[21] and the writer.[22] The limestone member of the series is mentioned in the greater number of the publications of the Geological Survey of Tasmania.

The limestone has a characteristic dark blue colour but gradations exist to a greyish tint. It is in places markedly fossiliferous. The texture is saccharoidal, the rock consisting of a mosaic of grey twinned calcite crystals. The impure varieties contain a little dolomite (up to 3%). The slates and quartzites occur towards the top of the series which is not less than 500 feet thick, the greater part of which is constituted by the limestone beds.

The distribution of this series is in scattered and discontinuous areas confined to that part of Tasmania lying westwards of a line joining S.W.Cape to Tamar Heads

The individual occurrences almost invariably are near the bottoms of valleys or in flat plains. They have been quarried at Queenstown, Zeehan, Darwin, Beaconsfield and Railton, and are well developed on the Gordon River where they form prominent cliffs.

(3). Sandstone and Slate Series.

Conformably overlying the Limestone Series occur white to grey sandstones associated with light-coloured and some dark-coloured slates. A horizon of soft yellow argillaceous sandstone occurs which is replete with fossils. This horizon and the white sandstones have supplied a fossil fauna which W.S.Dun has determined as belonging to the lower portion of the Silurian

This series is well developed in the Zeehan, Mt.Lyell, Jukes-Darwin and Middlesex districts. Its thickness is unknown but is not less than 1200 feet.

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(20) Loftus Hills Geol. Surv. Tas. Bulls 16 p 41 et seq; 19 p 26 et seq; 23 p 31 et seq
(21) Twelvetrees W H
+ Ward L. K. " " " " 8 pp 38-39
(22) Loftus Hills " " " " 16 pp 54-55

(d). PERMO-CARBONIFEROUS.

The Permo-Carboniferous system is highly developed in Tasmania. For the purposes of this work there is no need to do more than mention that they consist of a series of mudstones, limestones and sandstones with two horizons of coal seams (corresponding to the East Greta and Tomago series of New South Wales) and a characteristic basal glacial conglomerate containing boulders of all of the rocks ranging downwards from the Devonian granite. They are never folded and have at most a low dip but are much affected by block faulting. They are indicated in the geological map accompanying this work as a geologic unit combined with the Trias-Jura. The only occurrences which need be specially mentioned are the basal conglomerates & Lower Marine Mudstones on Mt. Sedgwick and the Eldon Range, and the basal conglomerates on Mt. Read at an elevation of 3200 feet above sea-level. These occurrences when taken in conjunction with the occurrence of the basal conglomerate and Lower Marine Mudstones at sea-level at Eden and the Henty River are of great significance in the reconstruction of the Tasmanian Batholith.

3. MESOZOIC.

TRIAS-JURA.

It is impossible to designate this system as either Triassic or Jurassic so the above nomenclature has been adopted. The rocks are sandstones, shales and mudstones all of fresh-water origin, together with important coal seams. They are unaffected by folding and coincide in dip and strike with the Permo-Carboniferous sedimentaries from which they are separated by a probable disconformity. The block faulting characteristic of the Permo-Carboniferous system affects the Trias-Jura system exactly in the same way.

4. TERTIARY.

With the exception of a local development of marine arenaceous limestones on the North West Coast the Tertiary sediments in Tasmania are fresh-water deposits. These are mainly confined to the Launceston Tertiary Basin which coincides with the Midlands-Westbury Plains topographic unit , the Derwent Tertiary Basin which is very much smaller and the Macquarie Harbour Tertiary Basin which is of about the same dimensions as the latter. In addition, there are isolated occurrences throughout the State of quite small extent, Amongst which may be mentioned the deep leads of the North East Coast carrying waterworn cassiterite which have been buried under the flows of Tertiary basalt.

B. - IGNEOUS ROCKS

1. - THE ROCKS OF THE PORPHYROID IGNEOUS COMPLEX.

(a). HOLOCRYSTALLINE FACIES.

(1). Acid and Sub-acid.- Typical granitic rocks occur at South Darwin (23) Dove River, Bond's Peak (24) and Farrell (25) These occurrences are indicated in Plate VII All of these rocks show normal granitic structure but have been altered by dynamic stresses and their original character has been to some extent masked by reconstitution. The crushing has subjected all the minerals to a state of strain and actual rupture has either taken place or the mineral now shows "wavy" or "shadowy" extinction. The occurrence of this "wavy" extinction of the quartz distinguishes these granites from all of the other granitic rocks of Tasmania.

The granites of South Darwin and Dove River consist of quartz, orthoclase (pink and white), oligoclase and biotite. The oligoclase is small in amount relatively to the orthoclase and both are chloritised - the former far more than the latter. The biotite also shows intense chloritisation and often is represented by aggregates of chlorite and epidote. Micropegmatitic or graphic structure is present.

The occurrences at Mt.Farrell consist of equidimensional crystals of dark-green biotite, hornblende, pink orthoclase and a pale greenish plagioclase and some quartz. The general character and alteration of the constituents are the same as in the case of the other rocks described above, and the hornblende is altered to an aggregate of chlorite and epidote. The rock is a syenite although gradations take place by increase of quartz into a type more closely approaching granite or perhaps a granodiorite. It should be observed, however, that the amount of dynamic strain and mineralogic reconstitution in these acid and sub-acid holocrystalline facies does not approach that which has been effected in the other facies of the complex.

(2). Basic.- In the Rocky River district in the neighbourhood of the Long Plains and near the mouth of the Forth River there occur a series of rocks which have been termed hornblendic or amphibolite schists and zoisite-amphibolite (26) The amphibolites and amphibolite schists consist of acid plagioclase (probably albite), green hornblende, apatite, garnet, quartz and epidote and occasionally zoisite. The plagioclase is often quite fresh-looking and occurs in large plates but at other times is much clouded, while the amphibole shows the extinction angles of common hornblende. Augite is sometimes present. The quartz is free from "shadowy" extinction and is obviously secondary. The hornblende shows no strain effects as does the augite when it occurs. The acid plagioclase is also clearly a secondary mineral. The zoisite-amphibolite contains little or no felspar, the constituent minerals being hornblende, garnet and zoisite with granular quartz. The texture of these rocks varies from distinctly banded or foliated to massive even granular. The banded or foliated varieties have the same constituents as the massive rocks but owe their distinctive character to these minerals, particularly the hornblende, being disposed with ~~in~~ their longer axes parallel. An examination of the field occurrence of these rocks and their microscopic structure

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(23) Loftus Hills Geol. Surv. Tas. Bull 16 pp 33-34
(24) Twelvetrees W.H. " " " " 14 pp 23-24
(25) Ward L.K. " " " " 3 p 10.
(26) Twelvetrees W.H. Proc. Aus. Ass. Adv. Sc. 1907

shows clearly that they have been subjected to great pressures and that the strain has resulted in considerable granulation and mineralogical reconstitution. Rock-flowage has undoubtedly produced the present foliation and this conclusion is indicative of the method by which the original character of the rock may be arrived at. Thus it is well established that under the conditions which bring about rock-flowage, or, in other words, during dynamic metamorphism augite is converted into hornblende with separation of lime and some silica, basic felspars into more acid felspars, particularly albite, and quartz with the concurrent development of epidote or zoisite or both.(27) Olivine changes to tremolite and talc, while Grubenmann ascribes the origin of garnet to this mineral. It is thus seen that the original constituents of these rocks were most probably augite and a basic plagioclase with a little olivine, the accessory minerals mentioned above, except the greater part of the magnetite which is an original constituent, representing the concomitant results of the chemical rearrangements which produced the four main constituents hornblende, albite, quartz and epidote. The original rock was therefore most probably a gabbro or a rock closely related thereto. This conclusion tallies with that arrived at after a study of the Porphyroid Igneous Complex regarded as representing a complete period of igneous activity.(28)

Holocrystalline basic rocks described by L.K.Ward from the Balfour district are to be included in this group of amphibolites. These latter rocks show no marked schistosity but the pyroxene has in most cases been converted to amphibole and the felspars which are andesine-labradorite to oligoclase-andesine have been largely albitised. They occur as dykes and less elongated masses of undetermined form intruding the Balfour slates and sandstones.

(b). FELSITIC AND PORPHYRITIC FACIES.

(a). Acid and Sub-acid. - The number of rock-types which are embraced under this category is a large one. They occur in almost endless variety in a belt extending from Mt.Darwin in the south along the West Coast Range through the Jukes, Huxley, Lyell, Sedgewick, Tundal, Read-Rosebery, Red Hills, Murchison and Farrell districts to the Middlesex district in the north. This belt is nowhere more than 5 miles in width and form a sinuous curve the general direction of which approximately parallels that of the geographic distribution of the West Coast Range Conglomerate series. This concordance in geographic distribution is given further expression in the association of the detached occurrence of the conglomerate series in the Zeehan district with the spilites of that district which are undoubted congenors of this group of rocks.

It is extremely difficult to satisfactorily name all of the numerous types of these acid and sub-acid rocks but they may be broadly designated as varieties of quartz-porphyry, felspar-porphyry, granite-porphyry, granophyre, felsite, keratophyre, quartz-keratophyre, quartz-porphyrite and spilite. Many such varieties have been described by the writer(30) L.K.Ward(31) and the late W.H.Twelvetrees.(29) They vary from fine-grained homogeneous felsitic rocks to distinctly porphyritic types. The porphyritic components are quartz or felspar or both. The porphyritic crystals are never very large seldom exceeding 1/8 inch in diameter, but they are sometimes set so closely together as to present an external aspect

(27) Leith + Mead, Metamorphic Geology p153.
(28) Vide infra p.
(29) Loftus Hills Geol. Surv. Tas. Bull 16 pp 34-37; 19 pp 12-13
(30) Ward L.K. " " " " 3 pp 11-16; 8 pp 15-18
(31) Twelvetrees W.H. " " " " 14 pp 24-26; Proc. Roy. Soc. Tas. 1898

resembling fine-grained granite. In colour these rocks vary from pure white to pink and red on the one hand and to dark green varieties on the other.

The mineralogic components are mainly quartz, oligoclase, albite a varying amount of orthoclase, chlorite, sericite, epidote and zoisite and, in the less acid varieties, augite and hornblende with some alteration products of these. The outstanding microscopic characters are in general the invariable evidences of mechanical deformation and mineralogic reconstitution, and in particular: the abundant development of secondary albite; the breaking down of the original felspars into quartz-sericite-chlorite, quartz-chlorite or quartz-sericite aggregates; the embayment and corrosion of many quartz phenocrysts, their undulatory extinction in other cases and their undoubted secondary character in still other occurrences; the quartz-albite-sericite aggregate which constitutes the ground-mass of many varieties; the granophyric and micro-felsitic nature of the ground mass in other types; the occurrence of filled vesicular cavities and the still recognisable fluidal structure; and the amphibolitisation of the pyroxenes.

Their chemical composition is indicated by the following analyses:-

Constituent	Acid (32)	Sub-Acid (33)
SiO_2	75.73	59.80
Al_2O_3	12.70	17.84
FeO	2.25	8.50
MgO	0.60	3.60
CaO	2.00	2.60
Na_2O	3.48	1.34
K_2O	2.04	2.67
Loss on ignition	1.20	2.50
	100.00	98.85

The most common mode of occurrence is in sheet-like masses although occasional dyke forms have been recognised. A noticeable characteristic is the prevalent gradual transition of one type into another. Thus one may pass from a red homogeneous felsitic rock by insensible gradations to a quartz-porphyry the ground-mass of whic is a dark green quartz-chlorite aggregate. Prominent too is the association of the sheet-like masses of the igneous rocks with alternating thin beds of argillaceous sediments, which are now slates, in such a manner as to unerringly point to their interstratification.

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(32) Quartz-keratophyre, Mt Read (W.F. Ward Analyst)
(33) Pyroxene-quartz-porphyry Lynchford (A.S. Wesley Analyst)

The evidence of their microscopic characters and that of their field relations and mode of occurrence combine in justifying the conclusion that these rocks represent a series of acid to sub-acid effusives which have been subjected to intense dynamic metamorphism and thereby have suffered structural rearrangements and mineralogic reconstitution.

(2). Basic.- A series of basic rocks occurs associated with the acid and sub-acid series in the Leven district[34] and at Mt. Lyell[35] and there is a development of them near Smithton which apparently has no acid or sub-acid associates. They are augite-plagioclase rocks, the accessory constituents of which may be hornblende, biotite or quartz. They resemble somewhat the Cretaceous diabase and the Tertiary basalt described below but the accessory components and the microscopic evidence of dynamic strain serve to disprove any genetic relationship.

Microscopic examination shows a quartzo-felspathic constituent of the ground-mass which is composed mainly of augite and plagioclase. Some at least of the granular quartz in the base is secondary and there are always signs of much crushing. It is impossible in the present state of our knowledge to give names to most of these rocks but an undoubted basalt occurs both at Leven and Smithton. Diabase occurs intruding the schists at Mt. Lyell as a small dyke but the greater number of occurrences of this basic facies is in the form of effusive sheets. The basalt at Smithton is important as containing metallic copper.

(c). MASSIVE FRAGMENTAL FACIES.

Occurring in intimate association with the acid, sub-acid and basic felsitic and porphyritic facies of the Porphyroid Igneous Complex are a remarkable series of fragmental volcanic rocks. There is a considerable range in types from a breccia consisting of angular fragments of distinctly varied colours to a dense massive rock resembling the quartz-porphyries described above which only discloses its fragmental character on the weathered surfaces.

(For continuation see p 19)

(d). SCHISTOSE FACIES.

Associated with the rocks of the Porphyroid Igneous Complex already described occur an abundant development of types showing the development of pronounced schistosity. The geographic distribution is coincident with that of the remaining types. The rock-types may be described as quartzitic, chloritic and sericitic schists. There are many variants from these types and transition rocks are common.

There is sometimes a tendency for the felsitic and porphyritic facies to assume a rude schistosity but the rocks of the schistose facies possess distinctive characters and highly developed foliation along parallel planes which are generally curved. The colour of these rocks varies from white to dark green and sometimes purple, the most common varieties having a grey, yellowish grey or green colour. Like the other facies of this igneous complex they show abundant evidences of intense crushing but they are distinctive in displaying, in addition, the distinctive character of intense shearing. In other words they show definite evidence of that

(continued on p. 20)

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34 Twelvetrees W. H. Geol. Surv. Tas. Bull 5 p. 13

35 Gregory J. W. "The Mt Lyell Mining Field" pp 58-59

The Dundas Breccia described by L.K.Ward (36) consists of an aggregate of angular fragments of chert, chalcedony and an igneous rock of the porphyroid series, the interstitial cement consisting of fragments of quartz, felspar, muscovite and chlorite. While mainly of fragmental igneous origin this rock has apparently been also partly formed by sediments. It occurs interbedded with the Dundas slates.

A very prevalent type consists of a deep green coloured base through which are irregularly scattered grey and red blotches. A variant of this type consists of the green coloured portion uniformly persistent for several feet irregularly scattered through which are irregularly shaped red masses upwards of a foot in diameter.

Another common variety is prevailingly green in colour which on the freshly broken surface appears homogeneous, but the weathered surface of which displays irregular fragments possessing the characters of the many varieties of acid and sub-acid felsitic and porphyritic rocks.

Microscopic examination shows that all of these rocks consist of heterogeneous fragments of varying sizes of the effusive facies of the Porphyroid Igneous rocks and possess the same general characteristics as these latter, particularly showing evidence of strong dynamic strain and reconstitution. Fragments of volcanic glass occur quite frequently. The fragments never seem to have been small enough to have constituted a tuff and the mineralogic reconstitution has universally affected all of these fragments to such an extent as to have brought about their coalescence into a solid massive rock. This coalescing action even has gone so far as to affect adjoining beds of lava and to have brought about an insensible gradation from a massive porphyry to a typical fragmental rock.

They have undoubtedly been derived by the shattering of the effusive rocks during their eruption and the resulting beds of heterogeneous fragments have assumed their form as the result of intense dynamic deformation and mineralogic reconstitution

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(36) Loc. cit. pp.34-35.

internal differential movement or shear which is essential to the development of schistosity. Thus in certain types the phenocrysts have been drawn out in augen and in others massive inclusions occur round which the schist planes curve in obvious lines of rock flowage.

The ground-mass of these rocks is often a quartz-albite-sericite or a quartz-albite-chlorite aggregate through which chlorite or sericite occurs in wavy zones or scattered shreds and patches. In other types the ground-mass consists of sericite disposed in wavy lines with lenticular masses of quartz-mosaic included therein. Felspathic material is very common and is so plentiful at times as to justify the designation of felspathic schist. These felspar fragments are invariably much decomposed and the mode of occurrence suggests the original form of the rock to have been a felspathic volcanic ash.

J.W.Gregory has described several varieties of these schists which occur at Mt.Lyell but he has failed to differentiate those schists which have been highly altered by the ore-bearing solutions in the vicinity of the ore-bodies from those not so affected. In consequence his descriptions lay too great a stress on the sericite component which has been produced by the sericitisation by ore-bearing solutions of an original chloritic-sericitic schist. However, his conclusions are important in that his conclusions coincide with those of the writer that these schists in a great number of cases at least were originally acid to sub-acid tuffs.

2. THE CONSTITUENT ROCKS OF THE TASMANIAN BATHOLITH.

(a). ACID AND SUB-ACID.

Rocks of acidic composition constitute the greater part of those portions of the Tasmanian batholith which are exposed at the surface. The prevailing rocks are granite with its various modifications and its consanguineous differentiates granite porphyry, pegmatite quartz-porphyry and aplite.

The normal granite is mostly of a porphyritic type. Large crystals of orthoclase one or two inches in diameter occur in a typical granitic matrix composed of quartz, orthoclase, plagioclase and biotite. Muscovite does not occur excepting where the normal granite has been affected by pneumatolitic action. By far the largest portion of the acid and sub-acid portion of the Tasmanian batholith is composed of this normal granite, which has been described in detail by L.L.Waterhouse for the occurrences in the Stanley River and Heemskirk districts. (37) The colour varies from white and grey to pink, depending on the colour of the felspars, but the pink variety merges into the white. The plagioclase is in this normal granite albite or the more acid varieties of plagioclase. The rock is remarkably fresh and shows very little alteration and there are no signs whatever of dynamic strain, thus differing essentially from the granite of the Porphyroid Igneous Complex.

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(37) Waterhouse L.L. Geol. Surv. Tas. Bulls: 15 pp 27-28; 21 pp 65-69

The variety which constitutes the Middlesex occurrences, however, is a monzonite, the orthoclase and plagioclase (oligoclase-andesine) being in about equal proportions.

The porphyritic texture characterises the more basic facies of the acid and sub-acid facies of the Tasmanian Batholith. Thus the rock-types occurring in two belts extending respectively from St.Marys through the Scamander district to St.Helens and from Diddleum to Lisle and Golconda have a porphyritic texture with a fine-grained granulitic ground-mass. These rocks are all varieties of granodiorite and occur in the neighbourhood of the contact of the granite massif with the Mathinna slates and sandstones.

Occupying ~~the marginal~~ portions of the granite of the Magnet and Meredith ranges there occur a series of sub-acid rocks ranging from hornblende-granite, through a granodiorite facies, to syenite. The change from one variety to another takes place ~~by insensible gradation~~ suddenly, constituting in general distinct intrusions, although at times gradations occur to a limited extent.

Traversing all of the acid and sub-acid rocks described above as well as the basic rocks described below, and extending into the older rocks into which the Tasmanian batholith has introduced itself, occur dykes of granite porphyry, quartz-porphyry, aplite and pegmatite together with occasional dykes of lamprophyre.

None of these rocks show evidence of dynamic strain and show no sign of the intense mineralogic reconstitution which is so characteristic of the acid and sub-acid rocks of the Porphyroid Igneous Complex.

(b). BASIC AND ULTRA-BASIC.

Extensive developments of basic and ultra-basic rocks occur on the West Coast between the Heemskirk district and Mt. Bischoff and, in addition, there are smaller outcrops south of Macquarie Harbour, east of the Gordon River and at Beaconsfield.

The number of rock-types is large and the following have been definitely recognised and described by the late W.H.Twelvetrees (38), L.K.Ward (39), L.L.Waterhouse (40) and A.McIntosh Reid (41).- Gabbro, norite, olivine norite, quartz norite, saussurite gabbro, saussurite-norite, gabbro-amphibolite together with the ultra-basic peridotites wehrlite and harzburgite, and the pyroxenites diallagite, bronzitite, websterite, websterite-porphyry and their alteration product serpentine. These constitute the basic and ultra-basic igneous massifs, the visible portions of which often consist of most of these rock-types occurring in intimate interassociation but which occasionally consist very largely of serpentine.

There is no need to describe the various rock-types enumerated above, but two of them call for special attention. These are the gabbro amphibolite and the serpentine.

The writer is of the opinion that the explanation by L.K. Ward (42) is sufficient to account for all of the mineral and structural alterations by which these basic rocks are formed from gabbro and amphibolite and which in no cases materially depart from the changes of amphibolitisation, saussuritisation and serpentinisation. These rocks differ markedly from the amphibolites and amphibolite-schists already described by reason of the absence of evidence of that intense dynamic strain and rock-flowage which characterises the latter rocks.

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(38) Twelvetrees W.H. Geol. Surv. Tas. Bull 17 pp 5-8
(39) Ward L.K " " " " 6 pp 18-24
(40) Waterhouse L.L. " " " " 15 pp 18-24; 21 pp 32-59
(41) Reid A.M. " " " " 32 pp 21-26
(42) Ward L.K " " " " 6 p 31.

3. THE CRETACEOUS DIABASE.

This rock covers approximately one-third of Tasmania constituting the greater portion of the surface of the Central Plateau and its detached massifs. In addition, it occurs at intervals all over the island.

The petrography of this rock has been much studied and the general description of the rock has been supplied by the late W.H. Twelvetrees (43) and Professor W.N.Benson, D.Sc. (44) The mineralogic components are plagioclase and pyroxene with a little magnetite, sometimes quartz, and occasionally hypersthene. Chlorite is always present in small amount. The plagioclase is a basic variety generally labradorite. The prevailing pyroxene is monoclinic, but a certain amount of orthorhombic pyroxenes have been observed in addition. The texture is characteristically ophitic. Du Toit (44a) has described this rock and its relationship to the South African dolerites.

The diabase is an intrusive rock and there is no evidence whatever of typical effusive characteristics. It occurs in huge sills 600 to 700 feet in thickness and definitely known to extend for some hundreds of square miles. In addition there occur more irregular bodies resembling asymmetric laccoliths. There also occur definite dyke-like masses.

The rock is intrusive into all rocks up to and including the Trias-Jura sediments and it is between the strata of this system and that of the Permo-Carboniferous that the huge sills have been laterally thrust. Silicification of the intruded sediments occurs at the contacts and where on the Central Plateau the few isolated remnants of overlying Trias-Jura sandstone occur they are found to be similarly affected.

As fragments of the diabase are found in the Tertiary sediments the age of the intrusion is pre-Tertiary but post-Trias-Jura. It is therefore regarded as of Cretaceous age, the intrusions being probably causally connected with the sinking in of Gondwana Land.

4. THE TERTIARY IGNEOUS ROCKS.

(a). THE PORT CYGNET ALKALINE INTRUSIVES.

In a belt 3 miles wide running North-East and South-West from Port Cygnet in the southern portion of Tasmania there occur an interesting series of acid to sub-acid holocrystalline to porphyritic rocks characterised by the soda-rich nepheline, hauyne, aegirine, analcime and sodic augite together with melanite garnet.

The rock-types of this alkaline series definitely recognised are:- elaeolite-syenite, alkali-syenite, tinguaite, tinguaite porphyry and solosbergite. They have been described by the late W.H.Twelvetrees (45) and ~~Professor W.N.Benson, D.Sc.~~ Dr E.F. Paul (46)

All of these rocks occurring in this alkaline belt are intrusive into Permo-Carboniferous sediments but numerous dykes have been observed intruding the Cretaceous diabase. (47) By this discovery Prof E.V. Skeats established the post Cretaceous age of these rocks.

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(43) Twelvetrees W.H. Proc. Aus. Ass. Adv. Sc. 1902 pp 287 – 291
(44) Benson W.N. Proc. Roy. Soc. Tas. pp 33-34
(45) Loc. cit pp 295 – 298
(46) Paul E.F. Mineral. Petr. Mitteil. Band 25 Heft IV Wien 1906
(47) Skeats E.W. Proc. Roy. Soc. Vic 1917 pp 155 – 164
(44a) Du Toit A.L. Proc. Roy. Soc. S. Africa 1919

(b). THE ALKALINE EFFUSIVES. -

It is especially noteworthy that the acid and sub-acid alkaline rocks of Tertiary age in Tasmania are all intrusive in character whilst the basic alkaline rocks are all effusive.

These alkaline effusives do not cover much area being limited to the trachydolerite at Circular Head and Table Cape on the North West Coast, occasional patches of limburgite also on the North West Coast and the interesting nepheline-augite rock of the Shannon Tier, and the melilite basalt of Southern Tasmania (One Tree Point etc).

(c). OLIVINE BASALT.

This is widespread throughout the island occurring as more or less continuous sheets of considerable areal extent and also as small but frequent and widely scattered patches. It is particularly strongly developed on the North, North-West, and North-East Coasts.

It is a normal olivine basalt with typical basaltic habit. The basalt wherever it is found associated with the Tertiary lacustrine series invariably overlies them.

Felspathic basalts occur in the vicinity of Brighton and other localities in the southern portion of the Midlands.

V. TECTONIC GEOLOGY AND THE PERIODS OF DIASTROPHISM AND IGNEOUS ACTIVITY.

A. - GENERAL PRINCIPLES.

1. PRELIMINARY EXPLANATION.

Before proceeding to describe the tectonics of Tasmania and before attempting to discuss the periods of diastrophism and the details of the concomitant igneous activity, it is desirable to clearly delineate certain fundamental principles which are accepted herein as the foundation on which the superstructure of this thesis is based.

The subjects which call for such special treatment are: Comagmatic series; petrogenic cycles; the sequence in a comagmatic series or petrogenic cycle; and the exact chronological relationship during an orogenic revolution or disturbance between the folding, faulting, development of schistosity and igneous invasion.

2. PETROGENIC CYCLES.

~~Taking~~ If be taken cognisance of the existence of comagmatic series simultaneously with that of petrogenic periods thus results the conception ~~results~~ of petrogenic cycles. This term combines the chronologic and material factors in petrogenesis and is proposed by the writer with a slightly different interpretation from that used by Daly (48) As used by the latter it is synonymous with petrogenic period but in view of the fact that a great number of petrogenic periods occur in which only one or two members of a comagmatic series are represented, it seems preferable to confine the use of the term petrogenic cycle to those petrogenic periods in which all or nearly all members of a comagmatic series are represented. As used in the present work it will have that meaning.

It seems that the sequence in an ideally complete normal petrogenic cycle is gabbro-diorite-quartz-diorite-granodiorite-granite in either batholithic, intrusive or effusive phases. This is the conception of the ideal petrogenic cycle adopted in the present investigation. Ejection from the magmatic hearth may take place at any stage of this differentiation which may either continue in subsidiary batholithic reservoirs or cease entirely on removal from the parental magmatic home according to the size of and the different physical conditions encountered by the ejected offshoots.

3. THE MECHANISM OF OROGENIC DISTURBANCES.

(a). OROGENIC CRUMPLING.

The structural failure of the geosyncline with its load of sediments initiates the active orogenic period. The manner of crumpling and the types of structure produced are too well known to need elaboration here (49)

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(48) ~~Loc. cit. p.56~~ Daly R.A. "Igneous Rocks + their origin" p56

(49) Pirsson, L.V., "Text-Book of Geology" 1915 pp.361-362.

Particular attention, however, is drawn to the fact that an overthrust is not necessarily towards the ~~old land mass~~ sea but may be in the reverse direction as has clearly occurred in the Appalachian Mountains in the United States.

(b). BATHOLITHIC PHASE.

It is generally and in fact universally recognised that orogenic belts are also areas of intense igneous activity which may take the form of either batholithic, intrusive or effusive phases.. It is essential, however, in order to adequately deal with the subject of metallogenesis, that a more exact conception of the relationship between orogenic crumpling - folding, thrust faulting, mechanical deformation and development of schistosity - and batholithic invasion should be developed, and particularly the exact chronologic relationship.

Daly (50) has sufficiently summarised the history of the world's batholithic intrusions in relation to orogenic movements to clearly demonstrate that, without known exception, they have immediately succeeded crustal deformation.

The questions demanding answers are these: Is the development of slaty cleavage and schistosity confined to orogenic and epeirogenic belts? At what stage in the orogenic disturbances is the schistosity developed? Is it complete with the initiation of thrust faulting or does it continue under conditions which combine both rock flowage and fracture? Is the batholithic invasion subsequent to or coincident with the thrust faulting?

The first question has been dealt with by Leith and Mead (51) who have shown that pressure due to depth alone is not adequate to cause rock flowage but that differential stresses are essential such as accompany orogenic and epeirogenic revolutions.

The two most comprehensive discussions in regard to the mechanism of orogenic revolutions and igneous invasion are those of Daly and Iddings in the works cited in the preceding pages. (52)

According to both hypotheses the batholithic phase succeeds the phase of overthrusting which in turn succeeds the folding and the development of schistosity, slaty cleavage and rock flowage. This conclusion is supported by the observed facts of succession whenever they have been closely studied. It does not concern us at this stage as to how the batholithic invasions work their way upwards whether by magmatic stoping or otherwise except that any pressure exerted by the magma seems to be of that magnitude equivalent to the gravitative effect of the crust since igneous magmas wherever they reach the surface apparently possess sufficient energy to reach the surface and no more.

It is to be specially noted that the larger batholithic intrusions will reach levels which can ordinarily be exposed by erosion, some time after the relief of compression as it takes time for the abyssal injection to work its way upwards to the zone which is cooling and suffering local contraction after the heating effect of the compressive forces and therefore offers the most favourable conditions for the invasion of the magma. It is also to be noted that the batholiths will be located within the orogenic belt and particularly at or near the principal axes of this belt.

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(50) Loc. cit. p.98
(51) Leith, C.K., Mead W.J. "Metamorphic Geology" p.179 and
Leith C.K. "Structural Geology"
(52) Iddings "The Problem of Volcanism" (Yale Univ Press)

B. - DETAILED DESCRIPTIONS.

I. THE PRE-CAMBRIAN TREND-LINES AND DIASTROPHISM.

As previously stated (53) the Pre-Cambrian system in Tasmania has not been sufficiently studied to permit of anything more detailed than a general description of it. This particularly applies to the structural geology and an attempt to map the trend-lines is found to be difficult owing to the absence of definite fixation of the fold axes of the system except in one or two isolated areas. The delineation of the trend-lines therefore is not permissible of more accurate accomplishment than that based on the general strike directions deciphered from a general survey of a much folded and contorted complex.

The Pre-Cambrian trend-lines shown in the accompanying tectonic map of Tasmania (Plate VII) are based on the summary of the observed strike directions by L.K.Ward (54) together with the observations by Benson at Cradle Mt. (55) and the writer between Macquarie Harbour and Point Hibbs (56). The responsibility for this interpretation is the writer's and he desires to draw particular attention to the pronounced bending in the vicinity of Cradle Mt. Benson has drawn attention to the possibility of the existence of a pronounced bend in the fold axes in this locality but does not follow the matter further. The strike of 22° to 67° indicated by Benson for Cradle Mt. itself is not indicated by the trend-lines shown, but cognisance has been taken of the fact that immediately to the north and south of that mountain the strike is 315° and 280° respectively. These latter are the dominating trend lines and the existence of the sharp bend constituting a marked plexus or knot accounts for the observations of Benson. The other bends in the trend-lines seem to be more gradual.

The structure of the lower horizon of the system is that of an intensely crumpled and folded complex qua-qua-versal folds being pronounced in certain areas. Benson has deduced for the Cradle Mt. district an overfold towards the east. The structure of the upper horizon is that of more gently folded beds with an absence of plication.

The general axis of the Pre-Cambrian orogenic devolution is that of a curved line having a general meridional direction with the direction of thrust apparently directed from the west. With the possible exception of certain pegmatite dykes in the Collingwood Valley there is no evidence of batholithic invasion following on this orogenic period.

2. - THE STRUCTURAL FEATURES AND ORIGIN OF THE PORPHYROID IGNEOUS COMPLEX.

(a). TECTONICS.

Before proceeding to deal with the origin of the Porphyroid Igneous Complex it is necessary to describe the main tectonic features of the Cambro-Ordovician system as a whole, i.e., to describe the trend lines common to both the sedimentary

(53) Vide supra p. 1[illegible]
(54) Ward L.K. "The Pre-Cambrian in Tasmania" Loc.cit. pp.147-151.
(55) Benson W.N. Loc.cit.
(56) Loftus Hills Geol.Surv.Tas. Bull 18 pp.8-9.

and igneous members of that system.

In only two localities has there been any definite delineation of the fold axes of the Cambro-Ordovician system. One such locality is in the Mathinna district where the late W.H.Twelvetrees located a single anticlinal axis having a bearing of from 335° to 340° (57). The other locality is in the Read-Rosebery district where the writer has mapped the fold axes ~~axes~~ in a belt 7 miles in length. (58) There are here two directions of fold axes approximately at right angles but the main tectonic axis bears 344° with a bend in the central part of the belt to 2°, beyond and northwards of which the 344° direction continues.

In attempting to decipher the trend-lines for the Cambro-Ordovician system in all other localities from descriptions published in the various bulletins of the Geological Survey of Tasmania, care must be taken or hopeless confusion will result from the fact that the strikes and dips indicated are sometimes those of the original beds and sometimes of the schist or cleavage planes. As the observations are too sporadic and widely scattered and altogether incomplete no attempt is possible to decipher the actual folds from the observed dips and strikes particularly as qua-qua versal folds are characteristic in certain areas. Reliance must therefore be solely based on observations of the strike of the schist planes or slaty cleavage except in cases where it has been specially noted that these are coincident with the bedding planes.

In the Mount Lyell district the schist planes are much confused owing to subsequent thrust faulting but the general direction is 310° to 315°. The schist planes in the Jukes-Darwin district south of Mount Lyell strike 340° on the average while in the southern portion of that district the granite belt has a trend of 360°. The Balfour slates and sandstones show a tendency to vary from a general trend of 345° near the Pieman to 315° near the Arthur River. The Dundas slates strike about 320° on the Long Plains and 315° on the Southern side of the Campbell Range on the upper Arthur River, while at Mt.Mueller and New River they have a trend of 320°. The slates at Mt. Farrell show a cleavage having a trend of 360°.. The regularly stratified series of porphyroids on the Leven River have a general trend of 315° while the slates and schists in the vicinity of Bell Mount in the Middlesex district show schist planes varying in strike from about 300° in the south-eastern portion to about 325° in the north-western part of the district. The Mathinna slates at Lefroy and Beaconsfield show cleavage planes striking approximately 315°. The trend of the dykes belonging to the Porphyroid Igneous Complex south-east of Cradle Mountain is in general 345°.

The writer has used these data in plotting the trend-lines of the Cambro-Ordovician system in the Tectonic Map which shows a general direction of 335°. ~~This tectonic line shows a general direction of 335°~~. This tectonic line shows a deviation towards the meridian in a belt extending from Williamsford through the Farrell district to the area lying immediately south-west of Cradle Mountain. It is noteworthy that it is in this belt and particularly in its western portion (the Read-Rosebery district) that the cross-folding occurs.

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(57) Twelvetrees W.H. "Report on Mathinna Goldfield" Part I 1906 pp.3-4
(58) Hills, Loftus, Loc. cit.

There is clearly a bending of the tectonic axis in this belt the direction changing from its general course to meridional and back again to its original trend. The longitudinal pressure occurring on the inside of this bend has given rise to the fold axes which cross the main axes at right angles in the Read-Rosebery district.

The main movement seems to have been towards the east as wherever overfolds have been observed they are overturned in that direction.

(b). THE EXTRUSIVE PHASE.

It has been shown (59) that the oldest units of the Cambro-Ordovician system are the Dundas Slate and Zeehan Slate series although the exact relationship between these series and the Balfour Slates and sandstones and the Mathinna Slates is as yet undetermined. These series are mainly sedimentary but contain interbedded tuffs and volcanic breccias together with occasional lava flows. When the geographical distribution of this series is recognised as indicating an area of at least 160 miles by 70 miles and the areas occupied by the other sedimentary series of the same system - the Balfour slates and sandstones and the Mathinna slates - are taken cognisance of, it is clear that all these sedimentary accumulations were laid down in a geosynclinal of some magnitude. The conformity of the pyroclastic deposits and the lava flows with the argillaceous and arenaceous sediments, which are now slates and sandstones, points to the conclusion that the volcanic activity was largely submarine. This was first clearly pointed out by L.K.Ward (60)

The Read-Rosebery schists are mainly of sedimentary origin but the igneous material included therein is undoubtedly pyroclastic in origin so that in this series which immediately overlies the Dundas slates there is evidence of the continuance of the volcanic activity being synchronous with the sedimentation. The Mount Lyell schists which probably occur on the same horizon as the Read-Rosebery schists are predominatingly igneous and most probably pyroclastic in origin.

The gradual transition through chloritic-quartzitic schists to the felsites, quartz-porphyries and related rocks shows a continuance of the accumulation of pyroclastic deposits until these were succeeded by actual lava flows. That these were largely submarine also is evidenced by their interbedded relationship to pyroclastic deposits of varying degrees of coarseness and undoubted sediments which are sometimes slates and sometimes silicified fine-grained bedded tuffs. The extrusion of these lavas and the accompanying sedimentation and accumulation of pyroclastic material mostly of the coarser grained type was apparently the final phase of the filling of the geosynclinal as no sediments are definitely known to conformably overlie them.

A fact of significance must be drawn attention to at this stage. The igneous phase of the Cambro-Ordovician system is not known eastward of the Middlesex district but finds its greatest development on the West and North-West Coasts, the main distribution extending, as previously pointed out (61) along a crescent stretching from the Jukes-Darwin district round the north-west of Cradle Mountain to Mounts Claud and Roland. A

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(59) Vide supra p.10
(60) Ward L.K., Geol.Surv.Tas Bull.6 p.38
(61) Vide supra p.16

possible explanation of this would be that a land surface existed off what is now the western coast-line of Tasmania: the eastern shore of that land-mass having a direction parallel to the trend-lines of the Cambro-Ordovician system in accordance with the principles enunciated above(62). There would thus be a corner of this land-mass pointing north-eastwards towards where Cradle Mountain now stands. If the volcanic activity occurred on this projection and on the sea floor in front of it, the present distribution of the Porphyroid Igneous Complex would be accounted for. This will be again referred to at a later stage when discussing the Cradle Tectonic Syntaxis(63)

Traversing the sedimentary and pyroclastic accumulations as well as the lava flows there occur many dykes similar in composition to the extrusive phases. These undoubtedly represent the feeders and offshoots therefrom which supplied the igneous material of those effusive phases.

The composition of the extrusive phase of the Porphyroid igneous complex now calls for consideration. As previously pointed out(64) there is a practically complete series of rocks from extremely acid quartz-porphyry and quartz-felsite through sub-acid varieties such as quartz-porphyrites, porphyrites, pyroxene-quartz-porphyry etc. to basic rocks of the basalt type. These constitute a comagmatic series minus the holocrystalline facies and a natural conclusion is that the Cambro-Ordovician petrogenic period constitutes a complete petrogenic cycle even without the holocrystalline types being taken into consideration. This conclusion is confirmed by the consideration that: (1) the basalts are associated with the Dundas slates on the Leven River which are the oldest series of the Cambro-Ordovician system; (2) the sub-acid porphyrites and their tuffs characterise the next succeeding Read-Rosebery and Mount Lyell schists; (3) the more acid facies occur in the uppermost portion of the system overlying the former series. The sequence is thus in accordance with that which characterises the majority of petrogenic cycles throughout the world.

(c). THE OROGENIC REVOLUTION AND THE SCHISTOSE PHASE.

Following upon the accumulation of sediments, pyroclastic deposits and lava flows, the total thickness of which was certainly not less than 20,000 feet and probably very much more, the sinking geosyncline collapsed and orogenic movement began.

During this orogenic paroxysm the whole of the sediments, pyroclastic accumulations and the lava flows were subjected to intense stress which was largely differential in character. Such stresses though varying from place to place would be everywhere great and would be operative upon the whole rock system. The question naturally arises: What has determined the conversion of some of the beds into schists while other beds showing evidence of equally great pressures are not schistose in structure although they have certainly suffered mineralogic reconstitution?

In answering this question it is advisable to first point out that the argillaceous sediments have been converted to slates while those that contained calcareous or finely divided igneous material have been converted to schists. It is clear, however, that the development of schists was not wholly confined to such beds. Certainly the suggestion made by Leith and Mead that the

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(62) Vide supra p.24
(63) Vide supra p.40
(64) Vide supra p. et seq

development of schists from igneous rocks is not the result of dynamic metamorphism of fresh igneous rocks but that they rather come from the katamorphosed phases of such rocks, is significant in this connection for the fine-grained tuffs would be more katamorphosed than the coarser varieties. The writer, however, while ascribing the origin of most of the schists to such a process believes nevertheless that another important determining condition was the position, during the differential movements, of any bed relatively to a more competent bed. This aspect of the problem has been discussed by the writer when dealing with the nature and mechanics of the folding and metamorphism of the Read-Rosebery schists and felsites (65) It is there pointed out that the felsite has acted as a competent bed, the relatively incompetent sediments of the Read-Rosebery schist series having been more intensely folded and constituting drag-folds.

It is important to note, however, that emphasis is placed upon the relative competence, and under sufficiently great pressures locally developed the weaker of two really competent beds may be converted to a schist, the locus of such action being where the stress differences are greatest. This has been the determining factor in the development of the amphibolite schists of the Rocky River where the original gabbro was relatively less competent than the adjacent Pre-Cambrian rocks and differential movement took place near their junction.

It is apparent that this Epi-Cambro-Ordovician orogenic period was characterised by great intensity of the compressive stresses and was operative over an area at least as large as the whole of Tasmania. As previously pointed out the axial lines of the folds parallel the coast-line of the land mass which in all probability lay off the west coast of Tasmania.

The metamorphism of the sediments, the pyroclastic deposits and the effusive rocks of the Cambro-Ordovician system was accomplished in great part during this orogenic paroxysm and before the appearance of the final acid batholithic phase which will now be discussed.

(d). THE FINAL BATHOLITHIC PHASE.

There has been described above a petrogenic cycle constituted by the effusive facies of the rocks of the Porphyroid Igneous complex. The question naturally arises: Are the plutonic facies of that cycle represented in the complex?

It is clearly evident from the descriptions given above that the granite of South Darwin, Farrell, Bonds Peak and Dove River and the syenite of Farrell constitute the acid and sub-acid holocrystalline rocks of the complex. The question naturally follows: Where are the basic holocrystalline members of this petrogenic cycle which, being complete in other respects, would be expected to show the basic phase as this would make it totally complete?

The fact that all the other members of the complex show marked effects of dynamic metamorphism would certainly lead to the expectation that this basic holocrystalline facies should show a similar metamorphism. Accordingly attention is directed

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(65) Loftus Hills, Geol.Surv.Tas. Bull.23 pp.43-51.
~~Vide infra p.~~
~~Vide supra p.~~

towards the dynamically altered amphibolite-schists, amphibolites and zoisite amphibolites of Rocky River and the lower Forth districts and the amphibolite dykes of Balfour. The amphibolite-schists and amphibolites together with the zoisite-amphibolites of the Rocky River district and the similar rocks near Hamilton near the mouth of the River Forth have been previously referred to the Pre-Cambrian (66). A significant fact, however, which throws doubt upon this conclusion is the fact that the trend lines of these schists are 340° as contrasted with the more nearly meridional direction of the Pre-Cambrian axes. This doubt becomes more definite when the similarity between the Balfour amphibolites and certain members of the Rocky River series is taken into consideration. As these rocks at Balfour occur as dykes penetrating the Balfour slates and sandstones which are certainly post Pre-Cambrian one fails to see why their lithological analogues should be separated from them and classed as Pre-Cambrian. Taking cognisance of these considerations together with those resulting from the conception of the complete petrogenic cycle of the porphyroid igneous complex the conclusion is justifiable that these amphibolite-schists are the metamorphosed forms of the holocrystalline basic phase of the Cambro-Ordovician petrogenic cycle.

At this stage consideration must be given to the fact that this holocrystalline phase has suffered more complete dynamic metamorphism than the acid and sub-acid holocrystalline phases. This is explicable on the basis of the principles indicated in the preliminary discussion of this chapter that the basic phase of a petrogenic cycle precedes the acid and sub-acid phases - actually demonstrated above in regard to the effusive members of the complex - and that the batholithic phase of an orogenic disturbance succeeds the development of schistosity and only takes place after the main compressive stresses have ceased to operate. It is apparent, therefore, that the holocrystalline basic members of the complex were intruded before the cessation of the orogenic movements and probably even before they began, since the occurrences are really large dyke-like masses rather than batholiths. It is also apparent that the granites, granodiorites and syenites came into their positions after the cessation of compression and the development of schistosity, this conclusion being confirmed by the granite contact crosscutting the schist planes in the adjoining schists and the occurrence of roof pendants of schists at South Darwin. (67) If this conclusion is correct it follows that the granite and syenite have not been subjected to the compression of the Epi-Cambro-Ordovician orogenic period and it becomes necessary to account for the existence of clear evidence of considerable compression in these rocks. As already pointed out the amount of compression evidenced by the present structure of these rocks has been much less than that suffered by the other facies of the complex. As will be seen below there is another important orogenic period - the Epi-Silurian - which has resulted in the compression of the whole of the Silurian sediments together with all the older geological units. Such compression was quite sufficient to produce the observed dynamic strains and mineralogic alterations in the granite granodiorite and syenite of the porphyroid igneous complex. The writer would therefore ascribe to the Epi-Silurian orogenic compression the development of whatever dynamic metamorphic characters the final acid and sub-acid batholithic phase of the porphyroid petrogenic cycle now possess. To the same orogenic period must also therefore be due some of the metamorphic characteristics of the other members of the porphyroid igneous complex, but that the decidedly greater part of their present schistosity was produced during the

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(66) Twelvetrees, W.H. Proc.Aus.Ass.Adv.Sc.1907.

(67) Vide Plate III

Epi-Cambro-Ordovician orogenic period is proved by the porphyroid pebbles which occur in the uncrushed portions of the West Coast Range conglomerate (the laying down of which preceded the Epi-Silurian orogenic period) possessing the same degree of schistosity as the occurrences of similar rocks in situ.

The actual outcrop of granite at South Darwin is too small to be called a batholith (68) and may be termed a stock. The Dove River occurrence is of larger dimensions and may be termed a batholith especially as it is probably continuous (although not necessarily in outcrop) with the granite at Bond's Peak.

In regard to the occurrences of these holocrystalline rocks at Farrell it is to be specially noted that the several varieties-granite, granodiorite, syenite - merge insensibly one into the other. The general mode of occurrence and the relationships of the several varieties is such as to suggest differentiation in situ with the formation of relatively basic border phases the acidity increasing inwards towards the central granite.

3. - THE EPI-SILURIAN OROGENIC DISTURBANCE.

(a). THE TECTONIC GEOLOGY OF THE SILURIAN SYSTEM.

The writer's researches in the Mt.Lyell district following upon those carried out by him in 1913 in the Jukes-Darwin district have thrown much light on the tectonic geology of the Silurian system.

In general the structure of the Silurian system is that of a series of folds along parallel axes. The folds are dominantly asymmetric and are frequently overturned. There is always a tendency for the overturned folds to break and in these localities upthrusting and overthrusting have taken place. This tendency is characteristic of the West Coast Range belt where the overfold of the West Coast Range conglomerate in the Jukes-Darwin district traced along the axis is found to break and upthrusting accompanied by considerable overthrusting is characteristic of the Lyell district while further to the north in the Tyndal district the anticline is almost unbroken and only slightly overturned. In such areas of overthrusting relatively stationary blocks have been compressed between the upthrust blocks and have been folded along axial lines approximately at right angles to the main axis. This has occurred in the Linda Valley at Mount Lyell. Moreover, there is in many places the development of qua-qua-versal folds and the main fold-axes invariably have a decided pitch which is undulatory in character.

In such complex structural arrangements as these and in the absence of any persistent or well defined cleavage or schistosity in the Silurian rocks, the delineation of the trend-lines depends on the interpretation of the structural features as a whole with the recognition of the main axial lines. In no district can disconnected observations of strike lines be used with safety in deciding upon the trend-lines of the Silurian system unless they be sufficient in number and the exposures sufficiently continuous to make possible the recognition of the master axes.

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(68) Daly R.A. Loc. cit. p.90.

Viewing the Silurian system from this standpoint the portion of it occurring on the West Coast Range and westwards towards Mt. Zeehan is seen to consist of two main axes of folding with folds of lesser dimensions between. The most persistent and pronounced fold axis is that of the West Coast Range where, as stated above, the fold is overturned to the east and in places broken and replaced by upthrusting and overthrusting. The axis of this fold is practically meridional there being a tendency in places to assume a deviation east of north. From Mt. Sorell in the South to Mt. Farrell in the north the axial direction is 5° which corresponds approximately with the direction of the range. The other main axis is that of Mt. Zeehan where the axial direction has a bearing of 315° but the fold is an unbroken anticlinal. It is important to note that this axial direction at Mt. Zeehan swings round to a little north of west to the north-west of the main mountain mass. The smaller fold axes to the east and west of the West Coast Range are naturally parallel to these dominating flexures and fractures.

The only other locality in which the Silurian system is sufficiently developed to permit of similar determination of the tectonic lines is the Middlesex and Mersey districts. In this area the fold axes vary from 270° to 320° and the system as a whole is in this area clearly characterised by trend-lines having a direction of 300°, this orientation corresponding again to the main trend of the mountain ridges. There is thus a pronounced swing of the trend-lines from the direction of 5° which characterises the whole of the West Coast Range. This change in direction clearly takes place somewhere in the latitude of Cradle Mountain. The manner of bending as interpreted by the writer is shown in the Tectonic Map. This interpretation is necessitated by the predominance of the westerly and north-westerly fold-axes over those having a north-easterly tendency which latter would predominate if the bending took place towards 120°.

This bend of 65° in the trend-lines of the Silurian system is a very pronounced one and it is important to note that the direction of the 300° trend-lines is apparently continued to the north-western coast line for a limestone belt having that direction persists practically to the sea-shore. This, although not conclusive, is significant when taken in conjunction with the strike of the fold axes on the Dial Range which is 335°.

(b). THE NATURE OF THE OROGENIC DISTURBANCE SUCCEEDING THE SILURIAN SEDIMENTATION.

The basal conglomerate of the Silurian system - the West Coast Range conglomerate - being a typical littoral deposit was, together with its sandstone members, laid down immediately off the shore-line of a land-mass. That strand-line is indicated by the present distribution of the conglomerate series, the direction of the coast-line being approximately parallel to the central line of the belt. Such central line has a direction east of north from the vicinity of the Frenchman's Cap to the Middlesex district beyond which it turns towards the north-west. It is to be specially noted that the Pre-Cambrian quartzites and mica-schists, which supplied the material of the conglomerate and associated sediments, occur throughout this belt.

The orogenic movements which succeeded the Silurian sedimentation were sufficiently extensive as to markedly affect the whole of the Silurian system exposed in Tasmania. The crustal adjustments which took place during the orogenic paroxysm were of the nature of intense folding with considerable over-folding and much thrust faulting accompanied by some overthrusting.

The direction of the overfolds and overthrusts is generally towards the eastwards but there is clear evidence of some up-thrusts having been caused by thrusts acting in the opposite direction. As indicated above, the positive segment (the land-mass supplying the sediments of the geosynclinal) was located to the westwards. The collapse and buckling of the geosyncline was accompanied by thrusts oppositely directed, i.e., both from the direction of the sea and also from the land-mass and either force may predominate locally. During this Epi-Silurian orogenic period the forces acting from the west seem to have preponderated over those from the east although there is distinct evidence of the existence of the latter.

Although the structural features produced by both the Epi-Pre-Cambrian and Epi-Cambro-Ordovician orogenic periods have not been delineated in detail, yet the knowledge already gained concerning them seems to indicate a marked difference between those two periods and the one now being considered. The observed thrusts, both vertical and horizontal, of any magnitude in the Pre-Cambrian and the Cambro-Ordovician systems are those which also affect the Silurian system and are therefore the result of the Epi-Silurian orogenic period. The absence of any pronounced thrusts in the rocks of the Pre-Cambrian and Cambro-Ordovician systems definitely referrable to the crustal deformation succeeding either period of sedimentation, taken in conjunction with the development of a regional schistosity or cleavage in the rocks of both systems and its absence from the Silurian, points to the conclusion that the pressures in the two earlier periods were more nearly tangential than those operating in the Epi-Silurian period.

The final phase of the Epi-Silurian orogenic period witnessed the greatest development of batholiths that has occurred in the geologic history of Tasmania. The whole of the island was the locus of batholithic invasion on a huge scale. Whether this was the direct result of the larger vertical component of the thrust as compared with the previous periods is conjectural but certainly probable. Whatever be the cause, however, the fact is clear that the Epi-Silurian period is characterised by a closing phase of immense batholithic invasion, the general character of which will now be described.

(c). THE ORIGIN AND STRUCTURE OF THE TASMANIAN BATHOLITH AND ITS SATELLITIC INJECTIONS.

The constituent rocks of the Tasmanian batholith have already been described and the visible outcrops are indicated in the general geological map (Plate VII) in which the basic facies is distinguished from the acid. It is necessary, however, before proceeding further to present the evidence on which the age determination is based.

In the first place there is sufficient petrographic relationship between the various facies of the acid portion on the one hand and between the different varieties of the basic portion on the other, to indicate that, whatever relationship may exist between the acid and basic facies, the several varieties and the disconnected occurrences of each portion - acid or basic - are derived from the same source and therefore

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~~Vide supra pp~~.

belong to the one petrogenic period. That this petrogenic period succeeded the Silurian is proved by the occurrence of contact metamorphism in Silurian limestone adjacent to the granite of the Middlesex district and the occurrence of serpentine intrusive into the Silurian rocks of the ~~Beaconsfield~~ Hazlewood district. That both the acid and basic facies preceded the Permo-Carboniferous is proved by the occurrence of boulders of granite, gabbro, etc., in the basal glacial conglomerates of that system. In the light of the discussions presented in the preceding pages, the natural conclusion is that the invasion of both the acid and basic facies was an accompaniment of the Epi-Silurian orogenic period and specifically signallised the final phase of that period.

The age, therefore, is Epi-Silurian. Previously this has been stated as Devonian but the writer prefers the designation Epi-Silurian as more definitely in conformity with the conception of the origin of batholiths in general. During the Devonian period Tasmania was a land surface undergoing a cycle of erosion which was of such duration and intensity as to result in the exposure to the surface of considerable portions of the batholith.

The question as to the relative order of invasion of the acid and basic facies has been somewhat fully dealt with by L.K. Ward(69), whose conclusions have been confirmed by L.L.Waterhouse after a study of the basic and acid plutonues of the Heemskirk district(70). The conclusion arrived at by Ward was that the basic facies although comagmatic with the acid types reached their mise en place and consolidated before the latter but that the time interval was only slight.

Using the conception of the petrogenic cycle as the method of approaching this question the facts indicate that the Epi-Silurian petrogenic cycle consisted of plutonic and intrusive phases only unless we assume that the effusive phase existed but has been wholly removed by erosion - a conclusion which scarcely seems probable in view of the absence of boulders of effusive rocks, definitely referable to this petrogenic period, in the Permo-Carboniferous basal conglomerates, although this being negative evidence must be used with caution. The Epi-Silurian petrogenic cycle is characterised by the normal sequence, being initiated by rocks of the gabbro clan and proceeding at intervals with the development of rocks of increasing acidity - granodiorite, granite, quartz-porphyry, aplite, pegmatite.

It is to be specially noted that the acid and basic facies occur very largely as separate outcrops although in places they are in contact and together constitute a composite massif. Such contacts, however, are sharp and indicate the intrusion of one rock into the other - on the evidence indicated above the acid being intrusive into the basic.

In all the geological maps and plans included in this work the acid facies is distinguished from the basic - the acid including also the sub-acid while the basic includes also the ultra-basic rocks.

The occurrencesof outcrops of these Epi-Silurian igneous rocks are numerous and of considerable extent as well as being distributed at intervals over the whole island.

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(69) Ward L.K., Geol.Surv.Tas. Bull 6 pp.29-30.
(70) Waterhouse L.L., Loc.cit. pp.98-99.

The following table contains a summary of the location, length, breadth and area of outcrop, direction of main axis, maximum height above sea level and the acid or basic character of the constituent rocks of the Epi-Silurian holocrystalline massifs of Tasmania. The massifs mentioned in this table are all shown in Plate VII Table I

1 Name of Massif	2 Length Miles	3 Width Miles	4 Area Square Miles	5 Direction of Main Axis	6 Present Maximum Height above Sea Level Feet	7 Original Maximum Height above Sea Level Feet	8 Constituent Rock Acid, Sub-acid or Basic
ue Tier	30	25	700	330°	2600	4600	Acid
ronach	32	8	250	340°	1250	3250	Acid
amander-Schouten Is.	60	4	240	350°	1500	3500	Acid & Sub-acic
n Lomond	10	7	70	320°	1500	3500	Acid
ria Island	10	2	20	350°	800	3800	Acid
.Paul's Dome	3	2	6	330°	1500	3500	Acid
aconsfield	5	1	5	320°	250	3250	Basic & Acid
sle-Patersonia	10	2	5	360°	1500	3500	Sub-Acid
ddlesex	3	2	5	330°	2300	2300	Acid
lion	1	0.5	0.5	350°	2300	2300	Acid
anite Tor	8	5	40	305°	3600	3600	Acid
mpshire Hills	8	7	50	350°	1500	4500	Acid
al Range	3	1	3	360°	800	3800	Acid
mpbell Range	3	2	5	320°	800	3800	Basic
redith Range	30	12	300	330°	2800	5800	Acid & Basic
ndas	5	2	10	315°	1100	4100	Basic
emskirk	10	6	45	320°	2800	5800	Acid & Basic
rth Pieman	20	2	30	330°	200	3200	Acid
cquarie Harbour	20	3	60	350°	600	3600	Basic
x's Bight	1	1	0.8	Circular	600	3600	Acid
yx River	1	0.3	0.3	350°	900	900	Basic
orentine River	1	0.3	0.3	350°	1000	1000	Basic
rdon River	2	0.5	1.0	350°	1200	1200	Basic
yes River	1	0.4	0.4	350°	1100	1100	Basic
nter Is.	11	2	20	350°	200	3200	Acid

Of these massifs nine have an area of outcrop of 40 square miles or over and therfore exceed the arbitrary minimum laid down by Daly as to the outcrop area of batholiths. The questions which naturally arise at this stage are these:-

(1) Are these nine larger massifs true batholiths or are they laccolithic in structure, or do they conform to the definition of chonoliths as laid down by Daly?

(2). What is the underground relationship between these massifs, large and small? Are they separate and distinct bodies only connected at depths so great as to be negligible in connection with the problem of metallogenesis or do they represent the exposed portions of the irregular surface of a continuous batholith of large dimensions?

(3). If this continuous batholith exists, what has determined the location of the upward projections or cupolas now exposed by erosion? What relation have they to the tectonics of Tasmania?

In dealing with these questions it is necessary to take cognisance of two important facts. The first of these is the occurrence of intrusive Epi-Silurian acid and basic rocks in addition to the plutonic massifs above described. Such intrusives occur in the Zeehan district as granite porphyry, aplite and mica-gabbro in the form of dykes having a general meridional trend; in the North Dundas district as granite porphyry (with a quartz-porphyry facies) and pegmatite, in dykes having a general orientation of 320°; in the Bischoff district as dykes and stocks of quartz-porphyry; in the Mount Claude district as quartz-porphyry dykes; in the Point Hibbs district as dykes and bosses of lamprophyre, and in the Mount Victoria field as quartz-porphyry dykes.

The second factor is one which has not previously been taken into consideration in discussions as to the Epi-Silurian plutonic geology but which is all-important therein as will be demonstrated below. This factor is the occurrence of block faulting on a huge scale bordering the Diabase Highlands and approximately paralleling the coast lines. The aggregate of such downthrow, which is on the seaward side of the Highlands, is as much as 3200 feet. As shown below these faults are of Tertiary age. In order therefore to form a true conception of the Epi-Silurian plutonic geology the downthrow blocks, together with the Epi-Silurian plutonic massifs contained therein, must be regarded as raised to the position they occupied before the faulting took place. When this is done it becomes possible to determine the relationships between the various plutonic massifs including their intrusive diaschistic dyke apophyses.

The approximate positions of these Tertiary faults are indicated in Plate II. Thus on the West Coast there exists to the west of the West Coast Range, but to the east of all of the massifs lying westward of the Granite Tor massif, a fault with a downthrow to the west of 3000 feet. For the reasons indicated below it is necessary to believe that the whole of ~~h~~ the block lying to the west of that fault plane has participated in the downward movement. The original position of all of the massifs contained in that block was therefore 3000 feet higher than at present. Similarly a fault plane with a downthrow of the same order of magnitude on the northern side runs parallel to the coast line to the northward of Mts. Claude and Roland

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~~Vide infra pp.~~

~~Vide infra p.~~

meeting the West Coast fault south of the Hampshire Hills. The Hampshire Hills massif must therefore be raised 3000 feet to restore it to its original position but the Middlesex, Pelion and Granite Tor massifs have not been included in this downward movement and are therefore approximately in their original positions.

On the North-East and East Coasts the interpretation is more difficult as the fault planes apparently cut the granite massifs themselves. Thus there is a fault plane to the north of Mt. Arthur probably running parallel to the coast-line which would drop the portion of the Stronach massif north of Mt. Stronach itself a distance of 3000 feet while the southern portion of the massif remains in its original position. A meridional fault occurs on the east side of Ben Lomond and downthrows the eastern half of that granite massif 2000 feet. A series of parallel faults occur east of this, the total effect of which is to drop the portion of the Scamander-Schouten Island massif lying east of St. Patrick's Head and the Maria Island massif another 1000 feet - making a total of 3000 feet. The effect of these faults on the Blue Tier massif is not quite clear but the general evidence points to the east-west fault north of Mt. Arthur meeting the Ben Lomond fault near the western limit of this (Blue Tier) massif and the major portion of it would therefore be dropped 2000 feet and the extreme eastern portion, being affected by the St. Patrick's Head fault, would have a total drop of 3000 feet. The central portion of this Blue Tier massif therefore must be raised 2000 feet to restore it to its original position.

In the southern portion of Tasmania it is doubtful whether the basic massifs between the Styx and Gordon Rivers have been affected by this block faulting, but it seems very probable that the granite massif at Cox's Bight is included in a block which has dropped approximately 3000 feet. Similarly the Beaconsfield massif on the northern coast must be raised by a similar amount to restore it to its original position.

These conclusions have been used in compiling column 7 in the Table I ~~on page~~ which gives the maximum height of each massif above sea-level before the Tertiary block faulting took place. These figures cannot be accepted as of greater accuracy than being within a few hundred feet of the exact height owing to the effects of warping, etc., not having been taken into account, but they are sufficiently near the truth to serve the purposes of this investigation.

A study of these figures when taken in conjunction with the fact that the present maximum elevation of the bottom of the basal glacial Permo-Carboniferous conglomerate is 3300 feet (near Cradle Mount), demonstrates the fact that at the beginning of the Permo-Carboniferous period the surface of Tasmania was a peneplain with the Heemskirk and Meredith Ranges, the Dundas + Granite Tor massif, the Hampshire Hills and the Blue Tier rising up above this peneplain as igneous monadnocks to approximate heights of 2700, 1000, 500 1300 and 1300 feet respectively. To these must be added the quartz-porphyry peak of Mt. Bischoff rising 2400 feet above the peneplain.

It is apparent therefore that the highest points reached by the Epi-Silurian plutonic invasions were in the Heemskirk, Granite Tor Meredith Range, Blue Tier and Dundas districts. How much higher than that indicated in the above table the igneous massifs extended in these localities is unknown, but obviously the original upper limit of the Heemskirk, Meredith Range, Granite Tor and Blue Tier massifs must have been considerably higher than the heights indicated, as they have clearly suffered much erosion since their sedimentary cover was removed.

It is now possible to proceed to answer the questions propounded above in regard to the structure and relationships of these igneous massifs.

The complete absence of any sign of the "doming" of the intruded sediments and the universally observed crosscutting and truncating of the strata by the igneous massifs supply definite evidence that none of these massifs is a laccolith.

L.K.Ward (71) has discussed the structure and relationships of the Heemskirk massif and arrived at the conclusion that it is a chonolith and has a definite bottom. He did not, however, take into consideration the fact that this Heemskirk massif is now 3200 feet lower than its true position relative to the Granite Tor and Middlesex massifs. As this fact greatly influences the conception of the relationships of these igneous massifs Ward's conclusion must be examined from this new viewpoint.

Ward's hypothesis that the Heemskirk massif possesses a definite bottom is very largely dependent on his conclusion that in the Heemskirk-Zeehan region there has been one single metallogenic epoch which ended quite suddenly. This latter conclusion will be fully discussed at a later stage of this work, but the deduction made from it as to the structure of the Heemskirk massif, although possibly correct in regard to that massif itself, does not justify Ward's chonolithic classification, in view of the original position of the whole massif having been 3000 feet higher than it is at present. Under these circumstances the solution of the problem of metallogenesis is possible through the conception of a main underlying batholith of which the Heemskirk massif is merely an upwardly projecting satellitic injection or cupola. This will be dealt with in detail when discussing the problem of metallogenesis in Chapter . It is the object at the present stage to confine attention to the structure of the Epi-Silurian plutonic rocks as decipherable from the occurrence and distribution of the rocks themselves.

It must be accepted as axiomatic that the occurrence of Epi-Silurian diaschistic dyke rocks indicate the existence of a plutonic mass at no great depth. Taking the known actual outcrops of the Epi-Silurian plutonic rocks together with the outcrops of the consanguineous dyke rocks the construction of the sections in Plate IV becomes possible.

The first section shows the existing structure on a line through Heemskirk, Zeehan, Dundas, Read~~bury~~, Farrel, Granite Tor, Middlesex, Beaconsfield and Blue Tier with the main faults indicated. The second section shows the restoration of the sunken blocks to their original positions, the original surface at the time of the plutonic invasion being also indicated.

It is clear from these sections that an underground connection exists between most of the surface outcrops.

Another line of section from Balfour through the Meredith Range to Granite Tor is shown in Plate V . The reconstruction along the main fault is also shown in the second section on this Plate. Again an obvious connection exists at no considerable depth beneath the surface between the Epi-Silurian igneous massifs.

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(71) Ward L.K., Proc.Aus.Ass.Adv.Science Vol.XIII pp.165-175.

Similar sections can be drawn on lines having any orientation whatsoever between Macquarie Harbour and Mt.Bischoff on the West Coast. If therefore we take the underground connection between the visible outcrops of Epi-Silurian plutonics shown in these sections into consideration and at the same time take cognisance of the frequency and area of their occurrence in this portion of Tasmania the conception naturally follows of a main batholith underlying at least that area in which the outcrops occur.

This conception is diametrically opposite to that indicated by L.Keith Ward(72). Ward's conclusion was based in the main on the consideration of the igneous outcrops and associated ore deposits along the line Heemskirk-Zeehan-Dundas-Rosebery-Farrell-Granite Tor-Middlesex. He made no attempt to explain in detail by his hypothesis the occurrences outside this one belt except to suggest a parallel line of crustal weakness to the northwards on the line of the section in Plate IV

In the preceding pages the lines of crustal weakness have been somewhat fully dealt with in delineating the tectonic lines characteristic of each diastrophic period. It is there shown that in the West Coast Region there exists a general parallelism of the tectonic lines for the three diastrophic periods, the prevailing direction being not many degrees divergent from meridional. Particularly it is desired to draw attention to the Epi-Silurian tectonic lines which are more nearly meridional than those of the two preceding periods.

Now there is shown in column 5 of Table I the orientation of the major axes of the outcrops of the Epi-Silurian plutonics and a study of these shows that they approximately coincide with the proved direction of the tectonic lines. This correspondence would probably be even more marked if the amount of denudation had permitted of outcrops more exactly indicative of the shape of the igneous masses. However, it is sufficiently apparent to clearly suggest a close connection between the shape and location of the igneous massifs and the tectonic lines. This concordance is in fact in complete accord with accepted principles as clearly pointed out by Daly(73).

The location of the igneous massifs and their elongation seems to be determined, therefore, by the Epi-Silurian tectonic lines and not by the hypothecated lines of crustal weakness indicated by L.Keith Ward which are at right angles thereto. As a matter of fact these two lines of weakness of Ward's are more apparent than real as is shown by the sections in Plates and and the many similar ones that can be drawn on almost any line in this region. Is there any explanation of this apparent direction of weakness which came under Ward's notice?

The answer to this question lies in the consideration of the Cradle Tectonic Syntaxis. In the descriptions given above of the tectonic lines of the three diastrophic periods it was shown that in each there is a distinct bend in the latitude of Cradle Mount. This indicates the existence of a knotting or bending point in this locality and therefore a zone of structural weakness. The writer regards this zone as being located between Rosebery and Cradle Mount with its centre approximately at Granite Tor. It is a zone which has shown a persistent crustal weakness and it therefore follows that the weakness extends to considerable depths.

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(72) Ward L.Keith Loc.cit.
(73) Daly R.A. "Igneous Rocks and Their Origin" p.94

From a consideration of these facts and the distribution of the Epi-Silurian igneous outcrops shown on the Geological Map the writer has formed the conception of this Cradle Tectonic Syntaxis as the central point of the upward invasion of the Epi-Silurian magma. Upwards through this zone of weakness the undifferentiated magma rose to a point far below any existing exposure where differentiation took place and the resulting differentiates - the basic and acid facies respectively - ultimately continued their upward passage into locations determined by the tectonic features developed during the slightly antecedent orogenic crumpling. In other words the long existent zone of weakness, termed the Cradle Tectonic Syntaxis, determined the locus or centre of a large Epi-Silurian composite batholith, the satellitic injections and cupolas of which had their mise en place determined by the major Epi-Silurian fold axes, which being characterised by an appreciable vertical component of movement provided zones of weakness up into which the magma was free to move. Thus is accounted for the higher positions of the more peripheral portions of the batholith as compared with the central focus.

It is specially to be noted that these higher portions of the upper surface of the batholith or cupolas coincide almost wholly with the locations of the monadnocks of the peneplain which characterised Tasmania at the beginning of the Permo-Carboniferous period. The significance of this will be considered later in relation to the mineral deposits which are also located at these high points.

The apparent line of weakness indicated by Ward is therefore to be regarded as the result of the confining of attention to a line of outcrops radiating outwards from the centre of the batholith. It is interesting to note that this "radiating" was observed by Ward when he drew attention to the two 'zones of mineralisation" meeting at Rosebery (74) although he did not give them the significance here indicated.

It is thus seen that the existence of the batholith suggested by the sections described above, is confirmed by a consideration of the igneous outcrops and the occurrence of a definite zone of crustal weakness which has acted as a magmatic focus. The writer regards this batholith as extending beneath that portion at least of the West Coast Region included ~~in a~~ between Macquarie Harbour and the Arthur River. It is most probably not circular and offshoots probably occur extending beyond the above limit, but it seems very probable that the main portion of the batholith which influences the consideration of the metallogenic problem is included ~~in~~ within the above ~~approximately circular area~~ limits.

If we now turn our attention to the other portion of Tasmania - the North-Eastern Region - which contains numerous outcrops of Epi-Silurian plutonics, the relatively large continuous areas of granite, taken in conjunction with the structure shown by the section in Plate IV, makes the conception of one large batholith inevitable. This batholith underlies the greater portion of north-eastern Tasmania and may be regarded as having an outline approximately circular, the centre lying somewhere between Mt. Victoria and Mathinna. This batholith, however, diverges from a circular outline in its eastern portion both to the north and the south as shown by the granite outcrops extending to Maria Island in the south and to Cape Portland and further to Cape Barron and Flinders Islands in the north.

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(74) Ward L. Keith, Proc. Aus. Ass. Adv. Science Vol. XIII p. 173.

This North-Eastern batholith is composite in character as is the West Coast batholith but there is a distinct difference in composition as is clear from the fact that the basic and ultrabasic facies so characteristic of the West Coast are apparently absent from the North-East, the most basic portion of this latter batholith consisting of granodiorite excepting the serpentine at Anderson's Creek.

~~The question now arises~~: ~~Is there any connection between these two batholiths~~?

~~A study of the section on Plate IV shows that such a connection is possible for cognisance must be taken of the basic and acid Epi-Silurian plutonics at Beaconsfield~~. ~~This connection is shown in the above section but any more definite proof than this cannot at present be adduced~~.

There still remains to be considered the isolated outcrops of small areal extent in the northern and south-western portion of the island. These are shown on the geological map but whether they have any underground connection at reasonable depth or are isolated intrusions or stocks there is no evidence to determine. As bearing on the metallogenic problem this question has no very great importance as the conception developed above as to the two batholiths ~~which are most probably connected~~ is the all-important conclusion as related to metallogenesis in Tasmania.

4. THE LATE MESOZOIC AND EARLY TERTIARY FAULTING.

In the preceding pages there has been mentioned the occurrence of tensional block faulting on a large scale all round Tasmania parallelling the coast line. This is demonstrated by the occurrence of Permo-Carboniferous sediments at sea level on the coast and at elevations of 3300 feet in the interior.

The exact details as to the respective roles played by the diabasic upthrust and tensional block faulting have not yet been worked out but sufficient is known to enable the fault map in Plate to be constructed. This map shows that the main peripheral faults with throws up to 3200 feet are of the tensional block fault type. The age of these is placed in the Early Tertiary as they are later than the diabase but earlier than the sediments of the Launceston Tertiary Basin. The positions of these fault lines shown on the map are approximate only but are sufficiently accurate for the purposes of the discussions relevant to the present investigation.

The effect of the diabasic upthrust is seen to be most marked to the east, south-east and north-east of the Central Plateau. As stated previously, the age of the development of this structural feature is late Mesozoic and most probably Cretaceous.

PART II.

METALLOGENESIS.

VI. DELINEATION OF THE METALLOGEOGRAPHIC PROVINCES OF TASMANIA.

In order to provide for the systematic study of the distribution of the ore deposits of Tasmania in time and space it is necessary, as an initial step, to consider them from the combined viewpoint of the predominant metal component and the portions of the island characterised by deposits of such metals.

This result can be achieved by plotting on a base map the localities in which deposits occur wherein a particular metal predominates or is the main economic component. It will then be found that certain areas can be defined which include groups of deposits of one predominant metal. These "provinces" merely express an areal association of deposits of particular metals and have not necessarily more than a geographical significance. They may therefore be termed "metallogeographic provinces", a term which indicates clearly the definite limitations of such provincial grouping in that it in no way whatever takes into consideration the genetic factor.

The above method has been adopted in preparing Plate which shows the metallogeographic of Tasmania for the more important metals. An examination of this map shows on the North-East Coast two large provinces - the Beaconsfield-Golconda-Mathinna gold province lying to the west of and adjacent to the important North-Eastern tin province which, towards the south, include associated tungsten. To the south-east of this prominent tin province lies the very much smaller tin province of Scamander with accompanying copper and silver provinces.

When we turn our attention to the West Coast, however, a much greater complexity of geographic distribution is observed. This complexity shows itself in a certain amount of overlapping but if attention is confined to the really dominant metals of the characteristic vein-types, it becomes noticeable rather in the form of interpenetration of the provinces. There is, however, a distinct demarcation between the various provinces as the map clearly shows. There is no need to mention each province here as the map shows them clearly and they are indicated, in addition, in Table III. It is sufficient to remark the penetration of the Savage-Wilson osmiridium province by the Parsons Hood-Bischoff tin province; the overlap and penetration of the West Coast Range iron province into the copper province of the same region; and the juxtaposition of the tin and the lead-silver provinces in the Heemskirk-Zeehan, Bischoff-Heazlewood, Granite Tor-Farrell and Middlesex-Round Hill regions.

VII. THE RELATION OF THE METALLOGEOGRAPHIC PROVINCES TO OUTCROPS OF PLUTONIC AND INTRUSIVE IGNEOUS ROCKS AND TO AREAS OF INTENSE OROGENIC MOVEMENT.

The next step in our metallogenic investigation is to discover any relationship which the metallogeographic provinces, delineated above, bear to outcrops of igneous rocks and zones of pronounced folding or orogenic movement. The data presented in Part I put this phase of our investigation on a sure footing and the relationships shown in Plate VII result from the simple superposition of the metallogeographic provinces of Plate on the main features of the igneous and tectonic geology of the region which includes within it the metallogeographic provinces.

There are shown in accordance with this plan the Epi-Silurian igneous rocks, both acid and basic, plutonic and intrusive; the plutonic members of the Porphyroid igneous complex as well as the intrusive and effusive members thereof; and the tectonic lines of the three orogenic periods. Neither the Tertiary basalt nor the Mesozoic diabase is shown on this map as a consideration of the general geological map taken in conjunction with that showing the metallogeographic provinces demonstrates clearly that there is no obvious relationship between these rocks and the majority, at least, of the ore deposits.

The examination of Plate VII shows that certain relationships are definitely suggested. Thus in the North-Eastern region the Beaconsfield-Golconda-Mathinna gold metallogeographic province follows faithfully the outcrops of the granodiorite facies of the Epi-Silurian acid plutonics, while the North-Eastern tin metallogeographic province corresponds to the Epi-Silurian granite area. In addition, the Scamander silver metallogeographic province occurs in proximity to the sub-acid facies of the Epi-Silurian granite.

Again in the southern region the Port Cygnet gold metallogeographic province is so related geographically to the alkaline intrusives of that region as to suggest a definite relationship.

When we turn to the West Coast region, however, such simple and obvious relationships are not deducible at a glance. The investigation in that region is made far more complicated by the fact, which at once becomes apparent, that the metallogeographic provinces could quite easily, as regards their geographic position, be related to either (1) the acid and sub-acid plutonic facies of the Porphyroid igneous complex; (2) the intrusive and effusive members of that complex; (3) the basic facies of Epi-Silurian plutonics, or (4) the acid facies of this latter igneous group. It cannot be decided on the type of evidence we are considering at this stage, whether the metallogeographic provinces are connected with any one of these possible igneous relatives more than another, for their geographic relationships would permit of relationships being assumed with any one of the above four igneous groups. From the preponderance, however, of the Epi-Silurian plutonics in areal extent it would to a certain extent be justifiable to indicate a probable relationship between them and those metallogeographic provinces lying to the north-west of a line joining Zeehan and Middlesex. Similarly a probable relationship would be indicated between the Porphyroid Igneous Complex and the metallogeographic provinces of the West

Coast Range although this will be rendered doubtful by the consideration of the Epi-Silurian orogenic zone which is coincident with the West Coast Range, to be mentioned below. Of special significance, however, although not necessarily justifying a conclusive decision, is the obvious fact that practically all of the more important ore deposits are included within ~~the two circles delineating~~ the two composite Epi-Silurian batholiths which, as indicated above, (~~and probably~~ which) may be connected ~~and~~ to form one large Tasmanian batholith.

It is clear, therefore, that the conclusions as to the actual relationship between the ore deposits and the various igneous groups cannot be deduced from a consideration of metallogeographic provinces and known igneous outcrops alone, although our investigation of the metallogenic problem has been definitely advanced thereby, by the suggestion of certain possible genetic associations indicated above. It is necessary therefore to approach the problem from many different aspects and this will be systematically dealt with in succeeding chapters.

Before leaving this present chapter, however, attention must be drawn to the two zones of intense Epi-Silurian orogenic movement indicated in Plate VII One of these coincides with the West Coast Range and the copper and iron metallogeographic provinces of that region. This would indicate a possible genetic connection which will be more fully considered and developed at a later stage . As stated above this conclusion is in opposition to a suggestion of a genetic connection with the Porphyroid igneous complex. The question thus arises: How far do these two apparently contradictory conclusions hold good? Which is correct? Or are both correct and consequently to what extent can the ore deposits of a metallogeographic province be divided into genetically related groups corresponding to this dual origin?

The other pronounced Epi-Silurian orogenic zone runs through Zeehan. This again suggests a genetic relationship and in this case it supplies a certain amount of confirmation of the relationship with the Epi-Silurian plutonics indicated above.

Having seen how these two tectonic features influence the metallogenic problem let us now enquire whether definite conclusions can be drawn from a consideration of the main tectonic lines in connection with the general orientation of the known lodes.

~~See below p.~~

VIII. THE RELATION BETWEEN THE FISSURE LODES AND THE TECTONIC LINES OF TASMANIA.

In dealing with the relationship between orientation of the ore deposits to the tectonic lines it is clearly necessary to confine our attention to those deposits which occur in definite fractures. It is obviously unsafe to make any such deductions in regard to an ore deposit which may be a replacement of a sedimentary bed or an igneous rock because such an ore-body may, because of the fortuitous local deviations from the general tectonics, have an orientation completely at variance with that characteristic of the tectonic lines of the particular orogenic epoch to which it belongs.

Accordingly there are plotted on Plates VIII and IX the more important lodes of portion of the West Coast region together with the Pre-Cambrian, Cambro-Ordovician and Silurian tectonic lines. There are shown in Plate VIII the more important lodes of Heemskirk, Zeehan, Five-Mile, Dundas, Curtin-Davis, Ringville, North-East Dundas, Stanley River and Farrell together with the Epi-Silurian dykes too small to be indicated on the general map. In Plate IX are shown the lodes of the Balfour area together with the Cambro-Ordovician- gabbro-amphibolite dykes.

It is apparent from a study of this plan that there is a general concordance between the orientation of the lodes and the general direction of the tectonic lines. The fact that these tectonic lines, belonging to three distinctly separate diastrophic periods, possess within a few degrees the same general direction, or, in other words, are practically superimposed on each other, would indicate the impossibility of definitely fixing a genetic relationship for any one of them with any particular lode or group of lodes. However, in the above plan there seems to be indicated a closer general parallelism of the lodes to the Epi-Silurian tectonic lines than to either of the other two, especially in the Zeehan-Dundas area.

No more definite deduction, therefore, can be made from a consideration of the relationship between the orientation of lodes and the tectonic lines than that of a possible closer relationship for the lodes whose direction has been plotted with the Epi-Silurian orogenic period than with either the Epi-Pre-Cambrian or Epi-Cambro-Ordovician.

IX. THE SEDIMENTARY AND IGNEOUS REPOSITORIES OF THE VARIOUS TYPES OF MINERAL DEPOSITS.

Before proceeding further in the investigation of the metallogenic problem it is necessary to indicate in which of the various geologic formations, dealt with in Part I, the respective types of mineral deposits are found. For this purpose ~~the following~~ table II has been compiled. The mineral deposits of Tasmania are in this table classified primarily on the basis of the dominant metal constituent, and secondarily on the dominant mineral components. A further division is shown based on the more prominent of the accessory constituents. The subdivision is carried further in many cases by taking cognisance of the presence of certain of the less plentiful accessory or gangue minerals in the ore, which nevertheless are developed to such a degree as to constitute a separate type of deposit. These four bases of classification are shown in the first four columns. The nature of the ore-body, whether a replacement, segregation, or a fissure filling, is indicated in column 4. The next column shows the locality or localities in which type is developed. The seventh column indicates the rock system or series in which each type is found, and the age of these repositories is given in column 8.

Up to the present stage of this investigation no attention has been paid to the mineral deposits in detail, the above discussions being based merely on geographic grouping of deposits of various metals. The metallogenic investigation, however, must take complete cognisance of the different types of mineral deposits in considerable detail. The initiation of this phase of the problem of metallogenesis is effected by means of the ~~following~~ table II which deals with all of the more important types of Tasmanian ore deposits.

In indicating the various ore deposits shown in this table no attempt has been made to make it a genetic classification. The ore deposits are simply indicated by their mineralogic composition and mode of occurrence, the genetic classification being intended to follow upon the study of this mineralogic composition combined with the association with the various lithological groups. Prominence is thus given to the mineral groupings for the deposits of the more important metals and in consequence in various parts of the table the same genetic group of deposits may be mentioned more than once or deposits indicated as separate types which are really variants of one type. The extent to which this has occurred will be demonstrated in the subsequent discussion.

X. THE EXTENT TO WHICH THE GENESIS OF THE MINERAL DEPOSITS IS CONCLUSIVELY DETERMINABLE FROM THE GEOLOGICAL AGE AND TECTONICS OF THE ROCKS IN WHICH THEY OCCUR.

(1). IN ROCKS OF PERMO-CARBONIFEROUS AND POST-PERMO-CARBONIFEROUS AGE.

We have seen above that the deductions to be drawn as to the age and genetic associations of the ore deposits of Tasmania from a consideration of their geographic relationships with igneous groups and tectonic lines, are definitely limited although a general conclusion points to a probable preponderating influence of the Epi-Silurian petrogenic and orogenic period. The metallogenic investigation will now be advanced to a further stage by considering the age of the lithological groups in which the respective ore deposits occur for it is obvious that those which are replacements or fissure fillings must be of a later age than their repositories, and, in the case of segregations, must be of the same age.

Table shows that there are only ~~three~~ four types of ore deposits in Tasmania in rocks of Permo-Carboniferous or younger age, viz.:

(1) The Quartz-Non-Auriferous Pyrite lodes of Ben Lomond;

(2). The quartz-haematite lodes of Dry's Bluff;

(3). The segregations of gold-bearing pyrite in diabase at Lawrenny;

(4). The chalcedony-auriferous pyrite lodes of Port Cygnet.

(1) Quartz-Non-Auriferous Pyrite Lodes of Ben Lomond. These lodes are described by G.A.Waller (75) who points out that they fill fractures in Permo-Carboniferous sediments. This fact combined with their close association with the diabase points definitely to a genetic association therewith. The age of these veins is therefore definitely fixed as Cretaceous.

(2). The quartz-haematite lodes at Drys Bluff occur in Trias-Jura sandstones in close proximity to the diabase and are obviously genetically connected therewith. Their age is therefore also Cretaceous.

(3). Auriferous Pyrite in Diabase. In only one locality has any mineral of possible economic value been found associated with diabase. This is at Lawrenny where in boring for coal, diabase was encountered carrying considerable pyrite giving in some samples assays at the rate of 2 ozs. of gold per ton. The occurrence is clearly a local segregation in the diabase and this mineral deposit is therefore also of Cretaceous age.

(4). Auriferous Pyrite-Chalcedony Lodes. These lodes occur in the Port Cygnet district in both Permo-Carboniferous mudstones and shales and the alkaline intrusives. They are generally located at the igneous contact and mineralisation has affected both intruded and intrusive rocks. A genetic association with this alkaline petrogenic period is therefore apparent. As these latter rocks are now known to be of Tertiary age as explained in Part I this type of ore deposit is of Tertiary age.

(75) Waller G.A. Report on Tin Mining District of Ben Lomond 1901 p.9.

(2). IN ROCKS OF SILURIAN AND EPI-SILURIAN AGE.

The very pronounced absence, with the ~~three~~ four isolated exceptions shown above, of ore deposits in rocks younger than Silurian or Epi-Silurian, viewed in conjunction with the widespread occurrence and innumerable exposures of diabase and basalt justifies the conclusion that neither of these igneous rocks is genetically associated with the main ore deposits of Tasmania. Similarly the restriction of the occurrence of the Tertiary alkaline series to one locality renders it at least highly improbable that this igneous period has contributed to ore deposition other than at Port Cygnet.

The conclusion seems perfectly sound, therefore, that an ore deposit occurring in Silurian or Epi-Silurian rocks as replacement, segregation or fissure filling is of Epi-Silurian age or even further that it is genetically connected with the Epi-Silurian batholithic period, provided genetic association with the igneous rocks is demonstrable.(76) In those cases in which such magmatic origin is not clear but in which solutions from other sources may have transported the mineral components to their present position in Silurian rocks, the upward limit of age may extend to the close of the Tertiary. If, however, boulders or pebbles of such deposits are found in the Permo-Carboniferous conglomerates the conclusion is justified that ore deposition took place during either the Epi-Silurian orogenic period or the batholithic end-point thereof. It is possible, therefore, to in this way definitely fix the age of those deposits which occur in Silurian and Epi-Silurian rocks.

Reference to Table II shows that the following types of ore deposits are known to occur in the sedimentary series of the Silurian period itself and the various igneous facies of the Epi-Silurian petrogenic period:-

(1). Magnetite-Diopside deposits of Comstock;

(2). Magnetite-Pyroxene-Garnet-Idocrase deposits of Middlesex and Heemskirk;

(3). Magnetite veins associated with asbestos at Beaconsfield;

(4). Blue-grey-Haematite ore-bodies of Blythe River and Dial Range. The magmatic origin of these deposits is doubtful but fragments of the typical ore have been found in the Permo-Carboniferous conglomerates at various points in the northern part of Tasmania.

(5). Specularite-Quartz veins so common in the beds of the West Coast Range Conglomerate series wherever they occur. In this case also the magmatic origin is doubtful, but again fragments have been found in the Permo-Carboniferous conglomerates in many localities.

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(76) There is no need to present details of the basis of this conclusion, for the genetic relationship between igneous magmas and certain ore deposits has been so fully demonstrated that a repetition of the evidence here would be superfluous. Neither is it deemed necessary to explain at this stage the full details of the conception which regards the mineralising solutions as among the final differentiates from the original magma which has given both the igneous rocks and the ore deposits, and therefore that ore deposits belonging to one metallogenic epoch may and often do occur within the various rock differentiates of the original magma.

(6). Cassiterite-Quartz-Pyrite-Sphalerite-Galena-Siderite-Tourmaline deposits of Heemskirk and Ben Lomond;

(7). Cassiterite-Quartz-Pyrrhotite-Pyrite ore-bodies of North Dundas and Bischoff;

(8). Cassiterite-Quartz-Tourmaline lodes of Heemskirk, North Dundas, Stanley River and Ben Lomond;

(9). Cassiterite-Quartz-Tourmaline-Topaz ore-bodies at Bischoff, Heemskirk and Ben Lomond;

(10). Cassiterite-Muscovite-Lepidolite (stanniferous greisen) deposits of Blue Tier, Gladstone, Roys Hill and Heemskirk;

(11). Cassiterite-bearing pegmatites of Ben Lomond and Blue Tier and the stanniferous porphyry of Bischoff;

(12). Wolframite-Quartz-Tourmaline lodes in the southern portion of the Balfour field and at Pelion and Ben Lomond;

(13). Wolframite-Quartz-Topaz lodes of Middlesex;

(14). Cassiterite-Wolframite-Quartz-Tourmaline lodes of Balfour and Pelion;

(15). Cassiterite-Wolframite-Quartz-Topaz lodes of Middlesex;

(16). Cassiterite-Wolframite-Bismuthinite-Quartz-Topaz lodes of Middlesex;

(17). Wolframite-Native Bismuth-Quartz-Topaz lodes of Middlesex;

(18). Chalcopyrite-Tourmaline-Fluorspar deposits of Heemskirk;
(19). Chalcopyrite-Pyrite-Barite ore-body of Lyell.
(20). Bornite-Chalcopyrite-Chalcocite-Quartx-Sericite ore-bodies of North Lyell;

(21). Bornite-Chalcopyrite-Barite-Haematite deposit at Lyell;

(22). Galena-Siderite-Jamesonite-Tetrahedrite lodes of eastern Zeehan and Mt.Claude;

(23). Galena-Dolomite-Manganiferous Siderite lodes of Magnet, Heazlewood and Dundas;

(24). Galena-Tourmaline-Quartz-Siderite-Tetrahedrite lode at Heemskirk;

(25). Arsenopyrite-Quartz veins at Scamander;

(26). Pentlandite-Pyrrhotite-Magnetite segregations at Heemskirk;

(27) Pentlandite-Pyrrhotite-Chalcopyrite lodes at Zeehan (5-Mile District);

(28). Osmiridium-chromite segregations in Serpentine in the Long Plains district.

The above deposits are therefore definitely fixed as of Epi-Silurian age. The existence is therefore established of an Epi-Silurian metallogenic epoch which gave rise to deposits characterised by the presence of tin, copper, lead, silver, nickel, osmiridium. This had been previously foreshadowed in our investigation after the consideration of igneous outcrops and tectonics in relation to metallogeographic provinces. The exact role this epoch has played in the history of ore deposition has not been stated in the above enumeration of ore deposits, the age of which is definitely determined by that of their repositories, for it still remains to be shown what relationship the ore-deposits, which occur in rocks older than Silurian, bear thereto and to any older metallogenic epoch.

(3). IN ROCKS OF CAMBRO-ORDOVICIAN AND EPI-CAMBRO-ORDOVICIAN AGE.

It is clear that ore deposits in rocks of Cambro-Ordovician or Epi-Cambro-Ordovician age may belong to either the Epi-Silurian metallogenic epoch or to an epoch of ore deposition of Epi-Cambro-Ordovician age.

The mere occurrence of any deposit in these Cambro-Ordovician rocks does therefore not prove anything definite and we must search for some special characteristic or mode of occurrence to enable any age determination to be made. Taking cognisance of the stratigraphic and tectonic geology of the Cambro-Ordovician and Silurian systems as fully delineated in Part I certain criteria can be formulated for such an age determination.

Pebbles and Boulders in West Coast Range Conglomerate.- The occurrence of fragments of ore, similar to that of ore-bodies in the Cambro-Ordovician rocks, in the conglomerates of this Silurian series is conclusive evidence that such ore-bodies are Cambro-Ordovician or Epi-Cambro-Ordovician in age.

Deformation of Ore Deposits.- An ore deposit in Cambro-Ordovician or Epi-Cambro-Ordovician rocks which shows definite evidence of deformation must clearly have existed before the Epi-Silurian orogenic movements and deformation took place. Such ore deposits are therefore of Cambro-Ordovician or Epi-Cambro-Ordovician age. This criterion, however, must be used with caution in so far as the replacement of schistose structures by ore may be mistaken for deformation of the ore deposit subsequent to deposition, although close investigation can distinguish between the two types without great difficulty.

In applying the first criterion to our investigation we are naturally restricted in our scope owing to the comparative small proportion of the whole conglomerate beds which is exposed or has been penetrated so as to make examination possible. Nevertheless observations in the Jukes-Darwin and Lyell districts have shown the following ore deposits to occur as rounded pebbles and boulders in the conglomerate in such positions as to show distinctly that they are not replacements of original pebbles of different composition;-

(1). Magnetite-Chlorite ore-bodies of South Darwin;

(2). Red Haematite ore-bodies of Jukes-Darwin;

(3). Chalcopyrite-Chlorite-Magnetite-Pyrite ore bodies of Mt. Darwin.

~~Vide supra p.~~

The age of these deposits is therefore Cambro-Ordovician or Epi-Cambro-Ordovician and the conception naturally follows of a definite Metallogenic Epoch of that age characterised mainly by iron but also supplying ~~more~~ some copper.

This conclusion is confirmed by applying the second criterion, for on the western side of the northern end of Mt. Jukes in an area characterised by intense Epi-Silurian deformation a deposit of red haematite occurs which shows definite deformation. This, however, is the only case at present known in which such deformation is definitely recognisable. It serves, however, to definitely fix these red haematite deposits as belonging to the Cambro-Ordovician or Epi-Cambro-Ordovician metallogenic epoch.

(4). IN ROCKS OF PRE-CAMBRIAN AGE.

Table II shows that very few indeed of our ore deposits occur in Pre-Cambrian rocks. Naturally such deposits could belong to any of the metallogenic epochs that succeeded the Pre-Cambrian period and, as will be shown in a subsequent chapter, the identity in mineralogical composition with deposits definitely referable to any of the metallogenic epochs indicated above, enable them to be precisely fixed as to age. These facts clearly indicate that practically no ore deposition took place in Pre-Cambrian time or during the Epi-Pre-Cambrian diastrophism. In other words, the great scarcity of ore deposits in Pre-Cambrian rocks taken in conjunction with the mineralogical composition of those that do occur proves that ore deposition in Tasmania did not commence until the Cambro-Ordovician. This conclusion is significant when it is considered in relation to the absence of Pre-Cambrian or Epi-Pre-Cambrian igneous rocks specially pointed out in Part I.

XI. FURTHER INVESTIGATION OF THE AGE OF ORE DEPOSITS IN PRE-SILURIAN ROCKS BASED ON MINERALOGIC ANALOGY TO DEPOSITS WHOSE AGE HAS ALREADY BEEN DETERMINED.

Reference to Table II will show that a considerable number of ore deposits have not been included in the age determination effected in the preceding chapter. In addition, it is to be noted that by far the greater number of these occur in rocks of Cambro-Ordovician or Epi-Cambro-Ordovician age. Attention must also be drawn to the fact that many are identical in mineralogic composition with some of the types for which the age has been determined in the preceding chapter, or so closely resemble them as to clearly indicate a distinct relationship. Such a relationship in mineralogic composition proints to a consanguinity of the ore-bearing solutions, and therefore a definite age relationship. It must be pointed out, however, that we are dealing at the present stage with a broad grouping as to age, namely that of main metallogenic epochs, the investigation of the different phases and stages of these main age groups being left for a subsequent chapter.

If, therefore, we take cognisance of these facts together with the occasional field observations of actual continuity of the deposit from Silurian into Cambro-Ordovician rocks, a method is suggested of fixing the age of additional ore deposits shown in the table. This method will now be applied.

A. EPI-SILURIAN.

(1). Magnetite-Pyroxene-Garnet-Idocrase ore-bodies at Heemskirk, near the eastern periphery of the granite. These resemble in mineralogic composition the similar deposits at the S. & M. Mine, Middlesex. They both occur close to the contact periphery of Epi-Silurian granite massifs.

(2). Cassiterite-Quartz-Pyrite-Sphalerite-Galena-Siderite Tourmaline ore-body at the Big Blow, Pelion. This deposit resembles similar deposits at Heemskirk and Ben Lomond sufficiently to warrant the conclusion of identity of origin.

(3). Wolframite-Quartz-Pyrite lodes of Upper Scamander, Ben Lomond (Gipps Creek) and the northern portion of Balfour resemble very closely the Wolframite-Quartz-Tourmaline lodes of Ben Lomond and southern Balfour respectively. At Gipps Creek the difference in mineralogic composition shown by these two types is seen to be developed in the ore lode as it is traced along its strike.

(4). Cassiterite-Wolframite-Quartz-Tourmaline lodes at Ben Lomond (Storey's Creek) are the replica of those at Balfour and, in addition, are obviously a variation of the neighbouring lodes in Epi-Silurian granite.

(5). Cassiterite-Wolframite-Quartz Topaz lodes of Gladstone have a close resemblance to similar lodes at Middlesex and like them are in close proximity to the Epi-Silurian granite periphery.

(6). Galena-Siderite-Jamesonite-Tetrahedrite lodes at Farrell, Dundas (Ringville), West Bischoff and Middlesex (Devon Mine) are identical in composition with those at Zeehan and Round Hill and can be regarded as belonging to the same metallogenic epoch.

(7). Galena-Pyrite-Jamesonite lodes sometimes carrying stannite and the Sphalerite-Galena-Pyrite-Siderite lodes of Zeehan; the Tetrahedrite- Pyrite-Galena, the Tetrahedrite-Pyrite-Chalcopyrite, and the Tetrahedrite-Siderite lodes of the Ringville district present such mineralogic and spatial affinities to the Epi-Silurian galena-siderite lodes on the one hand and amongst themselves on the other, as well as intermediate and gradational phases as to warrant their assignment to the same metallogenic epoch. This conclusion was formed by G.A.Waller (77) on similar grounds and has been generally accepted by subsequent observers. It is necessary, however, before the exact genetic relationships can be finally accepted, that these lodes, together with others to be similarly grouped below as to age, should be subjected to a detailed analysis based on their paragenesis and their time and spatial relationships within the main genetic groups which we are at this stage attempting to delineate.

(8). The Sphalerite-Galena-Pyrite-Chalcopyrite-Barite ore-bodies of the Read-Rosebery district present marked resemblances to the Chester ore-body and to the Epi-Silurian Chalcopyrite-Pyrite-Barite ore-body of Mount Lyell. In fact ore from the footwall of this latter ore-body where it is characterised by the special development of sphalerite and galena cannot be distinguished from portions of the Read-Rosebery ore-bodies. A genetic relationship between these deposits is therefore to be reasonably assumed.

(9). Sphalerite-Galena-Quartz-Chalcopyrite-Tetrahedrite veins occurring as offshoots of the main ore-bodies of Read-Rosebery are obviously of the same age.(78) These veins closely resemble the Galena-Quartz-Pyrite-Tetrahedrite lodes of the Success and Owen-Meredith Mines.

(10). Sphalerite-Galena-Pyrite-Tremolite and the Sphalerite-Galena-Diopside-Magnetite ore-bodies at Comstock, as pointed out by L.K.Ward (79) present such affinities to the Epi-Silurian ore deposits of that region as to warrant their inclusion in the same metallogenic epoch.

(11). Galena-Tourmaline-Quartz-Fluorite lodes at Rosebery bear sufficient mineralogic resemblance to the Galena-Tourmaline-Quartz-Siderite-Fluorite-Tetrahedrite lodes of the Globe Mine Heemskirk to warrant their being included in the same metallogenic epoch.

(12). The Chalcopyrite-Tourmaline-Fluorspar lodes at Rosebery resemble portions of the Epi-Silurian lode at the Globe Mine Heemskirk and can have the same general age assigned to them.

(13). Sphalerite-Galena-Pyrrhotite-Pyrite-Dolomite-Fluorite ore-bodies at North Dundas are assigned to the same group as similar Epi-Silurian cassiterite-bearing ore-bodies by L.K.Ward (80) who regards them as variations of the one vein-type. Mineralogic resemblances used by Ward as the basis of the above conclusion certainly justify their inclusion within one metallogenic epoch, but as will be seen subsequently not necessarily within the same phase of such epoch.

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(77) Waller G.A. Mineral Deposits (Other than Those of Tin) of North Dundas 1902

(78) Loftus Hills Geol.Surv.Tas. Bull.19 p.66

(79) Ward L.Keith Geol.Surv.Tas. Bull 8 p.67.

(80) Ward L.K. Geol.Surv.Tas.Bull 6 p.55

(14). Chalcopyrite-Quartz-Pyrrhotite-Arsenopyrite lodes at Scamander closely resemble the Epi-Silurian quartz-arsenopyrite lodes of the same district and clearly belong to the same age group.

D. EPI-CAMBRO-ORDOVICIAN.

(1). The Magnetite-Chlorite ore-bodies of Lake Dora, Red Hills, Tyndal and Mount Farrell are exactly similar to those at South Darwin determined above as of Epi-Ordovician age.

(2). Red Haematite ore-bodies at Lake Dora, Tyndal, Red Hills, Mt.Farrell resemble very closely the Epi-Cambro-Ordovician red haematites of Jukes-Darwin and a similar age is reasonably deducible for them also.

(3). Chalcopyrite-Chlorite-Magnetite-Pyrite ore-bodies in the same districts are the counterpart of those of Mt.Darwin and may be included in the Epi-Cambro-Ordovician metallogenic epoch. Gradations exist between these and similar ore-bodies carrying haematite and this combined with their close proximity to each other would suggest a definite genetic relationship. The Dove River deposits therefore are included in this determination.

XII. - THE EPI-SILURIAN METALLOGENIC EPOCH.

A. PRELIMINARY SUMMARY OF THE CONSTITUENT ORE DEPOSITS.

In the preceding pages there has been presented definite evidence of the Epi-Silurian age of a large number of the types of ore deposits of Tasmania. Before proceeding to further study the genetic relationships of the respective deposits within this age group it is desirable to briefly summarise the main types and localities.

(1). The whole of the tin, tungsten and bismuth deposits of Tasmania with the exception of the cassiterite-magnetite-pyrrhotite-hornblende-biotite-garnet-quartz deposits of Stanley River which, however, will be shown in the following discussion as to genesis to be also of this age.

(2). The whole of the lead, zinc and silver deposits.

(3). All of the nickel deposits.

(4). The magnetite ore-bodies of the Comstock-Moorookirk district.

(5). The haematite ore-bodies in the West Coast Range Conglomerate at Blythe and Dial Range and the West Coast Range generally.

(6). The lime-silicate gangue magnetite deposit at Middlesex.

(7). The Mount Lyell and North Lyell copper ore-bodies.

(8). The osmiridium deposits.

B. RELATIONSHIP TO THE METALLOGEOGRAPHIC PROVINCES.

The geographic grouping of the ore deposits of Tasmania considered at the initial stage of our investigation is now seen to possess a certain genetic significance.

The tin metallogeographic provinces of the North-East, North-West and West Coasts become, for example, metallogenic provinces of tin.

Similarly the metallogeographic provinces of nickel, osmiridium, lead-silver and zinc-lead-silver throughout Tasmania shown in Plate VI become the corresponding metallogenic provinces.

When, however, the iron and the copper metallogeographic provinces are examined from this new view-point no such general concordance is evident. In the case of the iron provinces there is such concordance for the Epi-Silurian metallogenic provinces of Blythe and Dial Range and Heemskirk but the iron metallogeographic province of the West Coast Range, clearly from the conclusions arrived at in the preceding chapters, consists of deposits belonging to widely separated metallogenic epochs and the geographic and genetic provinces do not correspond. The same applies to the West Coast Range copper metallogeographic province as some of the deposits in this geographic unit do not belong to the Epi-Silurian metallogenic epoch.

It is thus seen that the geographic is in certain cases an exact indicator of the Epi-Silurian genetic distribution, but the occurrence of a definite genetic superimposition in the West Coast Range iron and copper province prevents the application of this general concordance to Tasmania as a whole.

The exact details of the relationship of the geographic to the genetic provinces will be seen by referring to Table which will be developed in the succeeding pages.

C. RELATIONSHIP TO THE EPI-SILURIAN PETROGENIC PERIOD.

(1). GENERAL RELATIONSHIP.

If we take ~~Taking~~ cognisance of the respective ore-deposits within the Epi-Silurian metallogenic provinces which, corresponding to the metallogeographic provinces as indicated above, are shown in outline in Plate VII which also shows the outcrops of the rocks of the Epi-Silurian petrogenic period, A very close relationship to these Epi-Silurian igneous rocks becomes apparent. A study of this map and Table II shows that the various ore deposits occur either within the igneous rocks themselves or in close proximity thereto. In fact, with the exception of those Epi-Silurian ore deposits which occur on the West Coast Range no part of these metallogenic provinces occurs at a greater distance than two or three miles from an outcrop of Epi-Silurian igneous rock. A genetic relationship with the Epi-Silurian petrogenic period, actually foreshadowed when dealing with the relationship between the metallogeographic provinces and the igneous outcrops, is thus definitely indicated.

When the general relationship between ore deposits and igneous magmas now universally admitted is considered in connection with the above conclusion, the deduction is inevitable that the Epi-Silurian ore deposits are genetically related to the Epi-Silurian petrogenic period.

This conclusion having been arrived at, the more detailed investigation of the genetic relationship between the respective ore deposits and the various phases of the petrogenic period will now be proceeded with.

(2). RELATIONSHIP TO THE BASIC PHASE.

In Part I it has been shown that the basic phase initiated the Epi-Silurian petrogenic period. In Table II it has been shown that certain ore deposits occur as segregations in various rock facies of this basic phase. These are:-

(1). Osmiridium and gold in serpentine in the Long Plains, Savage River and Wilson River districts. This serpentine has been formed from ultra-basic phases of the basic plutonics such as peridotites.

(2). Nickel deposits at Heemskirk (Trial Harbour) and the Heazlewood districts. These consist of pentlandite-pyrrhotite-magnetite segregations in gabbro.

(3). Nickel lodes at the Five-Mile district near Zeehan. These consist of definite lode formations consisting of pentlandite-pyrrhotite-chalcopyrite and occur at the borders of pyroxenite dykes. They are injected sulphide segregations genetically associated with the pyroxenites but injected into definite fissures.

Obviously these ore deposits were formed concurrently with the intrusion of the basic phase of the petrogenic period and there results the definite conception of a basic phase of the Epi-Silurian metallogenic epoch. It is proposed to give this phase the designation of Basic Phase. It is not possible on the evidence available to further subdivide this metallogenic phase although it is possible that the ultra-basic facies carrying the osmiridium having crystallised first preceded the final consolidation of the gabbro and the resulting segregation of the nickeliferous sulphides.

It has been suggested (81) that some at least of the magnetite diopside deposits of Comstock are magmatic differentiates but the writer, after a careful examination, cannot confirm this as there exist too many discrepancies in the evidence. In the first place one would expect titaniferous magnetite as the characteristic differentiate in these basic rocks but the Comstock deposits are significantly devoid of titanium. In addition, the minerals garnet, vesuvianite and actinolite are not characteristic of magmatic segregations in basic rocks but rather of contact-metamorphic magnetite deposits. A third objection is the widespread occurrence of sphalerite intergrown with the magnetite which again is common in contact-metamorphic deposits and not in basic magmatic segregations. The diopside could belong to a basic rock but this mineral is characteristically developed in contact-metamorphic deposits. It is noteworthy that the magnetite deposits in various parts of the world which have been interpreted as magmatic differentiations occur in the sub-acid or quartz-free orthoclase porphyries and syenites and not in basic rocks the differentiates in which are as a rule either chromiferous (peridotite, etc.) or titaniferous (gabbro, etc.).

In short, the paragenesis of the constituent minerals and the fact that the ore-bodies occur not only in the basic rocks but more often in the sedimentaries, points rather to a contact-metamorphic origin than to magmatic segregation. Their occurrence at the granite contact itself and their restriction to a zone within one mile thereof, the majority being within one-third of a mile from the contact, point to a genetic connection with the granite. This will be discussed below when dealing with the acid phase. (82)

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(81) Reid A.M., Geol. Surv. Tas. Min. Res. No. 6 p. 82.

(82) Vide infra p.

(3). RELATIONSHIP TO THE ACID PHASE.

(a). The Outline of the Problem.

It is now clear that with the exception of the osmiridium and nickel deposits indicated above as belonging to the Basic Phase of the deposits summarised at the beginning of this chapter are genetically related to the acid phase of the Epi-Silurian petrogenic period. Such a relationship has been repeatedly suggested in the publications of the Geological Survey of Tasmania for all of these ore deposits and the systematic investigation of the subject described in the preceding pages leaves no room for doubt as to the justification of this conclusion. There definitely results therefore the conception of an Acid Phase of the Epi-Silurian metallogenic epoch.

There remains, however, the task of determining the details of this genetic relationship. The large number and variety of the ore deposits included in the Acid Phase demand a more complete analysis of the genetic relations than has been attempted up to the present. The factors entering into such an analysis are: the mode of irruption and differentiation of the acid phase of the composite batholith; the method by which the metal components became concentrated during the differentiation; the manner and succession in which the ore-bearing solutions were ejected from the magmatic hearth; the geographic variation of the metal constituents within the batholith; and the zonal precipitation from an ejected ore-bearing solution.

A complete statement of the genetic relationship must show how the above factors explain the existence of the Epi-Silurian metallogenic provinces indicated in the preceding pages. It must also include an explanation of the occurrence within a metallogenic province of ore deposits which are foreign thereto, for example, the zinc-lead lodes in a province characterised by a dominant tin content. It must account not only for the existence of the metallogenic province but of the occurrence and spatial arrangement of all of the component ore-deposits.

The first step towards a solution of these problems is obviously to consider the original surface configuration of the batholiths since the form of the uppermost first-cooled portion must have determined the manner in which the earlier differentiation and transfer of material would take place.

(b). The Effect of the Configuration of the Batholithic Roof.

In discussing the structure of the West Coast Batholith it was shown that the surface was extremely irregular rising into pronounced cupolas. This is shown in Plate IV + V

It was further pointed out that these cupolas coincided with a number of prominent monadnocks rising out of the peneplained surface of Tasmania at the beginning of the Permo-Carboniferous period. These monadnocks are Mt.Heemskirk, Meredith Range, North Dundas (Commonwealth Hill), Granite Tor, Mt.Bischoff, Hampshire Hills and Blue Tier.

From what has been demonstrated in the immediately preceding pages it will be observed that the chief Epi-Silurian metallogenic tin provinces occur in these very localities with the exception that the Hampshire Hills district has not yet been found to be markedly stanniferous. Such a coincidence repeated at the six most important tin-fields of Tasmania must surely possess a genetic significance. Such a genetic significance becomes inevitable when the further observation is taken into account that all of the other tin provinces coincide with granite cupolas rising distinctly although in a less pronounced manner above the surrounding surface of the batholith as at Middlesex, Pelion, Cox's Bight, Ben Lomond, and St.Paul's Dome.

The writer's investigations into this interesting fact have resulted in the conclusion that a simple explanation accounts for all of the observed occurrences and at the same time provides an adequate explanation of the spatial arrangement of the tin and iron deposits of the Epi-Silurian metallogenic period in relation to those of lead, zinc, silver and copper. This explanation will now be concisely stated and then examined in detail and applied to the respective ore deposits of the ~~Granite~~ Acid ~~Phase~~ Phase of the Epi-Silurian Metallogenic Epoch.

The final phases of the invasion of the batholith into the Cambro-Ordovician and Silurian sediments took place along axes of pronounced upwardly arched Epi-Silurian folds, peculiarly receptive to the magma. There were thus presented very favourable conditions for the easy transfer of the more gaseous components upwards into the cupolas which were themselves located in tectonic zones affected by a vertical component of movement and thus offering less resistance to the uprising magma. It is considered that a differential movement of the metalliferous and gaseous components took place in this manner, the more volatile compounds escaping upwards into the cupolas while the less mobile compounds remained inthe magma beneath the troughs separating the cupolas. The more volatile and essentially mobile compounds are those of tin and the "mineralisers" fluorine, boron, etc., together with those solutions or gases rich in iron which so universally gave rise to contact-metamorphic deposits. These, then, were the components which travelled upwards into the cupolas whence they were subsequently emitted as the magma proceeded to cool.[83] The lead, zinc, silver and copper compounds remained for the greater part beneath the trough and were similarly ejected from that horizon as cooling proceeded.

It would be expected, of course, that such solutions rising into the cupola would drag some lead, zinc, silver or copper with them and also that the trough horizon would still retain some of the elements largely transferred to the cupolas. This, we shall see, is in accordance with the facts when we examine the ore deposits related to the cupolas and troughs respectively.

We thus evolve the conception of two horizons of ore deposits belonging to the ~~Granite~~ Acid Phase of Epi-Silurian metallogenic epoch - (1) The Cupola Horizon, and (2) The Inter-Cupola Trough Horizon.

This conception is not entirely new as the transfer of volatile and gaseous components of a magma upwards in cupolas is demonstrated by B.S.Butler for the granite stocks of Utah[84] Ferguson and Bateman have shown that tin deposits commonly occur near the top of granite bodies[85]. The interpretation, as given

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[83] The quartz-tourmaline nodules in the granite of Heemskirk probably represent the arresting of the upward transfer late in its history by congealing of the magma, thus imprisoning the rising "gas globules" which crystallised as the quartz-tourmaline nodules.

[84] Butler,B.S., Econ.Geol. Vol.X p.101.

[85] Ferguson H.G. & Bateman A.M. Econ.Geol.Vol.7 p.223.

above, however, differs from these two conceptions in regard to the existence of the trough horizon in addition to that ~~in~~ the cupolas. The recognition of a two ~~trough~~ horizons is, however, indicated by J.B.Umpleby in arriving at the genesis of the Mackay copper deposits Idaho. In no case, however, has the combined conception been developed and the occurrences in Tasmania offer an excellent opportunity of demonstrating this new principle in metallogenesis.

Each horizon will now be examined in greater detail.

(c). <u>The Cupola Horizon</u>.

The ore deposits which occur in association with the cupolas are the following:-

(i) The magnetite lime-silicate ore-bodies at Heemskirk and Middlesex.

(ii). The cassiterite-magnetite-pyrrhotite-hornblende-biotite-garnet-quartz ore-bodies at the Mt.Lindsay mine, Stanley River.

(iii). The cassiterite-quartz lodes in all their varieties at all the localities shown in Table which incidentally include all the tin provinces of Tasmania.

(iv). The wolframite-quartz, the cassiterite-wolframite-quartz, the cassiterite-wolframite-bismuthinite-quartz, the wolframite-bismuthinite-quartz and the wolframite-native bismuth-quartz lodes also in all localities shown in Table II .

(v). The sphalerite-galena-diopside-magnetite ore-bodies at Heemskirk (Comstock).

(vi). The galena-tourmaline-quartz-siderite-fluorite-tetrahedrite lode at the Globe Mine Heemskirk

(vii). The sphalerite-galena-pyrrhotite-pyrite-dolomite-fluorite lodes at North Dundas.

(viii). The sphalerite-galena-garnet-actinolite-pyrrhotite lodes at North Dundas.

(ix). The chalcopyrite-quartz-pyrrhotite-arsenopyrite and arsenopyrite-quartz-pyrite lodes of Scamander.

(x). The chalcopyrite-axinite-actinolite-pyrrhotite ore-body at the Colebrook Mine (North Dundas) and the Barn-Bluff and Pelion district.

(xi). The gold-quartz lodes of Gladstone.

All of the above mentioned ore deposits occur in the localities already indicated as being the loci of cupolas.

<u>Contact Stage</u>.

In proceeding to determine the relative ages and relationships of these deposits the first deposits, which general conslusions of world-wide acceptance force upon our attention, are the magnetite-lime-silicate ore-bodies at Heemskirk and Middlesex and the cassiterite-magnetite-pyrrhotite-hornblende-

(86) Umpleby J.B. Econ. Geol. Vol IX p341 et seq.

biotite-garnet-quartz ore-bodies at the Mt.Lindsay mine, Stanley River. These are typical contact-metamorphic deposits. Such deposits are now accepted as the first mineralisation to result from granitic intrusions, and the Tasmanian occurrenced are no exception.

It is necessary to point out at this juncture that the Mt.Lindsay ore-body has not been fixed as to age in the preceding pages, but occurring as it does in the midst of a tin metallogenic province and in view of the conclusions as to genesis now developed in our investigation its inclusion in the Epi-Silurian metallogenic epoch becomes inescapable.

The Heemskirk deposits lie close to the granite contact, never in the granite itself but in the sedimentaries adjacent to it, being mostly within one mile of the visible contact. The spatial arrangement and paragenesis have lead Twelvetrees, Waller, Ward and Waterhouse to record their conclusions that they are contact-metamorphic deposits and, as pointed out above, this is confirmed by the writer.

It is to be noted that the Heemskirk contact-metamorphic deposits occur towards the lower portion of the cupola whereas the Middlesex deposits and the Mt.Lindsay ore-body are situated at a much higher position relative to the cupola. It is therefore significant that the Mt.Lindsay ore-body carries cassiterite and boron minerals, and the Middlesex deposits bismuthinite, while the Heemskirk ore-bodies are devoid of these minerals. This fact indicates that within the cupola itself the differential movement of the tin continued and this metal with its "mineralisers" boron, etc., became concentrated in the higher parts of the cupolas.

In regard to the mineralogic composition of these contact-metamorphic deposits an important fact is the occurrence at Heemskirk of sphalerite and galena closely associated with and to some extent intergrown with the magnetite and lime-silicate components. It is evident that the contact stage of the Cupola Horizon at Heemskirk included some sphalerite and galena deposition. Whether all of the sphalerite-galena ore-bodies of the Comstock district belong to the contact stage is extremely doubtful as some of them most probably belong to the subsequent zinc-lead stage of the Cupola Horizon.

The bismuthinite associated with the pyroxene-garnet-idocrase deposits at Middlesex is so intergrown with the other constituents as to show a simultaneous deposition. The contact stage in this locality therefore included a small amount of bismuth in the magmatic emanations.

The cassiterite in the Mt.Lindsay ore-body has been clearly shown by Waterhouse (87) to represent a distinctly later mineralisation than the magnetite and the greater portion of the lime-magnesia silicate component. In addition, the cassiterite-wolframite-bismuthinite lodes of Middlesex fill fissures in the contact-metamorphic deposit and are subsequent thereto. These facts taken in conjunction with the absence of tin from the Comstock deposits and their being outside the granite and never within it point to the contact stage being the first deposition of mineral deposits occurring in the cupolas and that this stage preceded the tin stage. This is in accordance with conclusions in other parts of the world but it is not intended to attempt to further subdivide this stage as has been attempted for many contact-metamorphic deposits in America.

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(87) Waterhouse L.L., Geol. Surv.Tas. Bull 15 p.71 et seq.

The haematite-magnetite-quartz lode at Nelson River is in close proximity to the Cupola and the origin of this ore-body is therefore ascribed to the contact stage. The absence of high temperature gangue minerals must be taken as indicative of deposition under somewhat cooler conditions than those mentioned above.

The Contact Stage therefore consisted of the deposition of magnetite and accompanying lime-silicate minerals together with a little sphalerite and galena as Heemskirk and a small amount of bismuthinite at Middlesex.

Tin Stage.

The tin, tungsten and bismuth deposits occur both within the granite and in the intruded rocks. It is therefore evident that after the upward transfer of the more mobile constituents and subsequent to the initial emanations from the liquid magma which gave rise to the Contact Stage, differentiation commenced, accompanied by a "backward concentration" of the more siliceous portion of the magma together with the metallic constituents and "mineralocers". The outer portion of the Cupola consolidated and subsequent cooling and contraction provided channels along which were ejected the non-centrated tin, tungsten and bismuth, silica, boron, fluorine, etc., constituents. Thus were deposited with a few exceptions the tin, tungsten and bismuth deposits shown above as belonging to the Cupola Horizon. The formation of these deposits therefore constitutes a definite Tin State in the Cupola Horizon.

There is no indication of the existence of a zonal deposition in the lodes of this Tin Stage. Certainly in the Gipps Creek district at Ben Lomond a lode can be traced from the sedimentaries into the granite which shows a change from predominant cassiterite to predominant wolframite in that direction. Contradicting this, however, are the occurrences at Middlesex where the reverse happens in several instances although no general variation of this kind exists there being no zonal relation according to distance from the granite.

At the Mt.Rex Mine, Ben Lomond, there is an indication that the galena content of the ore-body is higher in the upper levels although nothing definite in this regard can be stated.

In places the pyrite and other sulphide components have increased with depth but this is generally accounted for by the influence of surface agencies excepting the case of the Giblin lode at Mt.Bischoff where the sulphides apparently increase in depth.

In fact, the whole of the observations point to the conclusion that in this Tin Stage the ejection of the gaseous- and liquid emanations was sudden, that the deposition was of the same general character throughout any one fissure, any variations that exist within a lode being due to fortuitous differences in composition of the solutions at different portions of the lode, and that the supply of ore-bearing material ceased as abruptly as it began owing to the closing by contraction of the opening connecting with the intra-cupola focus.

The mineralogic variation displayed by the various tin, tungsten and bismuth deposits we are now considering must accordingly be attributed to the heterogeneous distribution within the magma constituting the cupola. This heterogeneity is due to iriginal sporadic distribution of the elements in the magma accentuated by the results of segregation within the cupola. Heterogeneity on a larger scale becomes apparent on comparing the deposits of the various cupolas, e.g., the prevailing cassiterite-quartz-tourmaline lodes of Heemskirk, the characteristic cassiterite-quartz-pyrrhotite-pyrite orebodies of North Dundas, the cassiterite-quartz-tourmaline-topaz lodes of Mt.Bischoff, the absence of tourmaline and the presence of topaz at Middlesex and the absence of tourmaline at Blue Tier.

If, however, this heterogeneous variation is pointed to as the explanation of the occurrence of the cassiterite-quartz-pyrite-sphalerite-galena-siderite-tourmaline lodes of the Sweeneys and Globe Mines at Heemskirk and the Big Blow Lode at Pelion, the galena-tourmaline-quartz-siderite-fluorite-tetrahedrite lode at Globe Mine Heemskirk, the sphalerite-galena-pyrrhotite-pyrite-dolomite-fluorite lodes of North Dundas, such difficulties are presented as to make this explanation highly improbable. Certainly, as pointed out by L.K.Ward (88) the cassiterite-quartz-pyrrhotite-pyrite deposits at North Dundas carry a little galena and sphalerite but the difference in composition of the two general types is so great and their distance apart asshown in Plate VIII so small that on the assumption of their all belonging to the Tin Stage such heterogeneity at the focus as is demanded by the differences in composition of the lodes could scarcely be imagined in such a small area.

The proximity of the two general types and the great difference in composition could be accounted for on the basis of zonal variation combined with an inward migration of zones towards the focus but this would involve the conception of a long-time interval between their respective depositions. As stated above, however, there is no evidence justifying the conclusion that appreciable zonal deposition has occurred and the conclusion is forced upon us that the sphalerite-galena and similar lodes represent a later stage of ore deposition. The fact of their occurrence in completely separate lode channels is evidence of an independent origin.

The writer would here point out the danger of the common practice of concluding that, because two different types of deposits contain one or more minerals in common, they have been deposited from the same solutions. Before arriving at a conclusion as to the origin or identity of the depositing solutions other factors have to be considered, as already shown above, besides mineralogic composition. The mistake so often made in this connection is thus to conclude that the depositing solutions are identical when actually they are merely consanguineous and were ejected from the magmatic hearth at stages separated by a definite time interval.

During this time interval the cooling of the magma and its sedimentary aureole proceeded and concurrent differentiation took place. This would continue until the accumulated strains, consequent upon cooling, produced fissures along new lines which were determined by the same tectonic conditions as those previously formed. These new fissures extending towards the magmatic hearth at last reached the backwardly concentrated metal components which, thus released, travelled along the new channels and, depositing their mineral constituents, gave rise to the next metallogenic stage.

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(88) Ward L.K., Geol.Surv.Tas. Bull. 6 p. 55.

The conception therefore results of a third stage of ore deposition within this Cupola Horizon, which is specially distinguished by the presence of zinc, lead and copper. It is thus termed the Zinc-Lead-Copper Stage and it will now be considered.

Zinc-Lead-Copper Stage.

The deposits of this stage occur in both the granite of the cupola and its sedimentary aureole. They include the lodes at Heemskirk, North Dundas and Pelion just mentioned. These lodes have not been observed to crosscut the lodes of the Tin Stage but this being negative evidence cannot be made the basis of a decision as to genesis.

When, however, we extend our attention to other metallogenic provinces than the two dealt with above, additional knowledge of this Zinc-Lead-Copper Stage is acquired. Thus in the Gladstone district there occur a series of gold-quartz lodes which, as pointed out by Twelvetrees, being high-temperature deposits are of a totally different type from the common gold-quartz lodes of North Eastern Tasmania.(89) One of these lodes occurs crosscutting a tin-wolfram lode and displacing it. In these lodes cassiterite occurs sporadically as well as sphalerite, galena and arsenopyrite. They are therefore later than the Tin Stage but their spatial arrangement and their cassiterite content connect them with the Cupola Horizon and they are thus included in the Zinc-Lead-Copper Stage being regarded as a variant thereof due to geographic variation within the magma.

The chalcopyrite-quartz-pyrrhotite-arsenopyrite and the arsenopyrite-quartz-pyrite lodes of Scamander are also high temperature lodes and associated as they are with the tin and tungsten deposits their grouping into the Cupola Horizon is justified. They belong in fact to the Zinc-Lead-Copper Stage of the Cupola Horizon varying from the other deposits referred to this stage in the chalcopyrite content although sphalerite and galena are typically present. This variation is again due to geographic variation within the magma. These lodes show a definite tendency to zonal distribution as the deeper portions show the chalcopyrite-quartz-pyrrhotite-arsenopyrite type while the upper portion consists of the arsenopyrite-quartz-pyrite type. Locally sphalerite and galena are abundant but this is ascribed to fortuitous variation in the composition of the solutions within the lode. This zonal variation corresponds to that at Butte Montana as worked out by Billingsley and Grimes.(90)

~~Realising~~ If it be realised that this Zinc-Lead-Copper Stage exists the explanation of certain other deposits becomes apparent. Thus there are the sphalerite-galena-garnet-actinolite lodes of North Dundas, the chalcopyrite-axinite-actinolite ~~lodes of Kort~~ pyrrhotite ore-body at the Colebrook Mine (North Dundas) which also contains sphalerite and galena in small quantities and the similar lodes at Pelion and Barn Bluff, and the chalcopyrite-tourmaline-fluorspar lode at the Globe Mine (Heemskirk), all of which occur within the cupolas and are high temperature deposits but, being devoid of tin and characterised rather by zinc, lead or copper, were most probably deposited during the Zinc-Lead-Copper Stage. This is indicated very clearly by the Colebrook occurrence which, although containing high temperature minerals axinite, datolite, etc., formed by boron, fluorine, etc. emanations, yet carries no cassiterite although within a few hundred feet there is a

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(89) Twelvetrees W.H., Geol.Surv.Tas. Bull 9 p.29

(90) Billingsley P. & Grimes J.A. Trans. Am.Inst.Min.Eng.Vol.LVIII p.313 et seq.

cassiterite-quartz lode. Heterogeneity at the focus cannot account for such combined proximity of position and divergence of composition as this and the reference of them to the Zinc-Lead-Copper Stage becomes essential. When to this consideration their mineralogic resemblances, their spatial arrangement and their occurrence within the cupola area are added, the placing of all of these deposits in the Zinc-Lead-Copper Stage is inevitable.

The chalcopyrite-quartz-ferriferous dolomite lodes of the Balfour region now come up for consideration. They are located in close proximity to the tin-tungsten province and the region is the locus of a cupola which probably extends eastwards beyond the Balfour Range and rises upwards within it as the presence of tin deposits at Balfour itself seem to clearly indicate. The assumed outline of the base of the cupola is shown in Plate VII. The copper lides of Balfour thus seem to represent a geographic variant of the zinc-lead-copper stage. Although chalcopyrite is the normal econoc mineral yet variants occur containing appreciable galena, some sphalerite and at times magnetite and haematite. The presence of magnetite in these lodes, the existence of a definite passage type carrying cassiterite, chalcopyrite, magnetite and garnet, and the spatial relationships thus justify their inclusion in the Zinc-Lead-Copper Stage of the Cupola Horizon.

With the deposition of the mineral constituents of the lodes of the Zinc-Lead-Copper Stage the mineralisation associated with the Cupolas ceased. This sudden cessation was caused by the exhaustion of the metal constituents and the complete consolidation of the cupola. It is interesting to note that a sudden cessation of ore deposition was deduced by Ward for the whole of the Heemskirk-Zeehan area and a conclusion was made by him that the Heemskirk-Zeehan massif had a definite bottom. The conception presented above shows that Ward's observation is correct if applied to the Cupola Horizon but not necessarily, as we whall see later, as applied to the Inter-Cupola Trough Horizon. Ward's chonolith would correspond to the Heemskirk cupola if he had not extended its base eastwards of the Comstock. In fact the low temperature deposits of the Inter-Cupola Troughs, to be now described, show that ore deposition continued after the sudden cessation of the high temperature pneumatolytic stages of the Cupolas and that the Acid Phase of the Metallogenic Epoch, regarded as a whole, continued progressively from the highest temprature to relatively low temperature conditions. The sudden ending of ejection of solutions and sealing up of the reservoir were confined to the Cupola.

(d). <u>The Inter-Cupola Trough Horizon.</u>

In the troughs between the cupolas there occur the following ore deposits which have been assigned above to the Epi-Silurian Metallogenic Epoch:-

(i). Galena-pyrite-jamesonite lodes at Pastkutchen's, Susannite and the pyritic lodes of Montana Mine, Zeehan.

(ii). Sphalerite-galena-pyrite-siderite of the Western portion of the Zeehan field.

(iii). Galena-siderite-jamesonite-tetrahedrite lodes of Central and Eastern Zeehan, Farrell, Mt. Claude, Middlesex and West Bischoff.

(iv). Galena-dolomite-manganiferous siderite lodes of the Magnet and Heazlewood and the Kapi Mine, Dundas.

(v). Sphalerite-galena-pyrite-chalcopyrite-barite-quartz ore-bodies of the Read-Rosebery-Chester-Mt. Block region.

(vi). Galena-quarta-pyrite lodes at Success and Owen Meredith Mines, Dundas, Silver Cliffs and Heazlewood in Waratah district and Tasman and Lyell Extended Mines, Mt. Lyell.

(vii). Sphalerite-galena-quartz-chalcopyrite-tetrahedrite lodes of Read-Rosebery.

(viii). Tetrahedrite-siderite lodes of the eastern portion of Ringville district Dundas.

(ix). Tetrahedrite-pyrite-chalcopyrite lodes of Ring Valley Mine Ringville.

(x). Tetrahedrite-pyrite-galena lodes of the Curtin-Davis mines Ringville.

(xi). Pyrargyrite-barite ore-body at Hercules Mine Mt. Read.

(xii). Arsenopyrite-siderite-pyrite lodes at Ringville.

(xiii). Chalcopyrite-pyrite-barite-quartz ore-bodies at Mt. Lyell and Chester.

(xiv). Bornite-barite-haematite ore-body at Lyell Blocks.

(xv). Chalcopyrite-tourmaline-fluorite lodes at Rosebery.

(xvi). Galena-tourmaline-quartz-fluorite lode at Rosebery.

(xvii). Stannite-quartz-pyrite-chalcopyrite lode at Oonah Mine, Zeehan.

(xviii). Chalcopyrite-quartz-pyrite lode at Oonah Mine, Zeehan.

It is clear that such a diversity of lode types as this list represents could not have been deposited under the same conditions of temperature and pressure and therefore that they must have been deposited either at different distances from the magmatic hearth or at different stages in the cooling and differentiation of the magma. They occur in separate lode channels there being no change in either a vertical or horizontal direction within any one lode from one type to another. Two markedly different lode types at times occur in close proximity and at the same level and therefore at equal distances from the magmatic hearth.

As in the case of the Tin Stage and Zinc-Lead-Copper Stage of the Cupola Horizon this indicates a definite time interval and a complete change in the identity of the fissure along which the magmatic solutions were ejected. Consequently the conception has been formed of a series of Stages during which solutions were ejected from the magmatic hearth, each Stage being characterised by solutions of different composition which have been responsible for the several main types. It would naturally be expected that at any particular distance above the batholithic surface of the trough each successive stage would be characterised by minerals of a lower temperature condition than are those of its predecessor.

It must be remembered that we are now dealing with deposits in the sedimentary rocks situated at much greater distances from the igneous contact than is the case in the cupolas and therefore that the ore deposits would be expected to be on the whole of lower temperature conditions than those of the cupolas. In the cases in Tasmania where the batholith has been exposed in the troughs there occur none of the ore deposits characteristic of the Cupola Horizon. Although this is negative evidence it points to the conclusion that the transfer of the more mobile and volatile constituents to the cupolas was almost complete and very little was left in the trough to give rise to such ore deposits at that horizon. In spite therefore of the fact that the ore deposits of this horizon are in general at greater distances from the surface of the batholith than those of the Cupola Horizon, yet the conclusion is indicated that even in closer proximity to the batholithic surface there do not exist deposits corresponding to them.

The several Stages of this Inter-Cupola Trough Horizon which include the ore deposits enumerated above will now be considered.

Tin-Tourmaline Stage.

The ore deposits belonging to this stage are not those of the typical high temperature or pneumatolytic type but rather those which were deposited under hydato-pneumatolytic or relatively cooler conditions of the general high temperature zone.

The ore deposits included in this High Temperature Stage are the chalcopyrite-tourmaline-fluorite and the galena-tourmaline-quartz-fluorite lodes at Rosebery, and the stannite-quartz-pyrite-chalcopyrite lode at the Oonah Mine Zeehan.

The tourmaline and fluorite of the two former lode types serve to definitely place them as of high temperature origin. They carry no tin but bismuthinite is present in one lode. The possess quite distinctive features which serve to separate them from the lodes of the Zinc-Lead-Copper Stage of the Cupola Horizon and must be regarded as having been deposited from solutions ejected from the magma at the end of the first stage of the backward concentration subsequent to the initial transfer of the more mobile constituents upwards to the cupolas. These solutions contained whatever of the more mobile components remained in the trough after the upward transfer to the cupola. We would naturally expect them to contain tin somewhere in the regional variations and this is what actually happens, the representative ore deposit and region being the Oonah stannite lodes.

The fact needs explanation that the stanniferous pyrrhotite ore-bodies of North Dundas contain cassiterite finely disseminated in massive pyrrhotite, whereas the tin in the Oonah lode is in the form of stannite. According to F.W.Clarke sulphides of tin arsenic and antimony are more soluble in alkaline sulphide solutions than other sulphides. If therefore the same solutions were responsible for both these types of deposits as held by L.K.Ward, we would expect the markedly sulphidic solutions which deposited the pyrrhotite to have carried the tin to a cooler zone and deposited it as the complex sulphide stannite as has happened at the Oonah Mine. That this is not so clearly indicates that totally different solutions were responsible for these two types of ore deposits -

one solution carrying the mineralisers from which cassiterite was formed and very little alkaline sulphide while the other was essentially an alkaline sulphide solution.

This consideration leads us to the conclusion already indicated that these two types of ore deposits belong to distinct stages within the metallogenic epoch. The occurrence of the stannite lodes within the inter-cupola trough thus naturally leads to the deduction that they belong to the Inter-Cupola Trough Horizon and represent that variant of the earlier higher temperature stage thereof which carried the tin, tungsten and bismuth residue remaining at this horizon after the upward transfer to the cupola had taken place. The solutions, although carrying these metals, did not contain sufficient mineralisers to permit of the deposition of the tin as cassiterite, being rich in alkaline sulphides. It is important to remember here that the stannite lodes carry wolframite and bismuthinite, together with a very little fluorite and cassiterite.

It is significant to note that in regard to the Bolivian deposits carrying stannite W. Myron Davy (91) has arrived at the conclusion that the solutions which deposited stannite were quite distinct from those which were responsible for the cassiterite lodes and that deposition took place under conditions of temperature lower than those at which the cassiterite lodes were formed.

The Tin-Tourmaline Stage of the Inter-Cupola Horizon as represented by any deposits at present known therefore was of somewhat lower temperature than at least the earlier stages of the Cupola Horizon. Variation in the type of lode was the result of regional variation within the magma, any tin remaining therein after the cupola transfer being ultimately deposited from an alkaline sulphide solution as stannite and not as cassiterite.

<u>Siliceous-Lead-Zinc-Copper Stage.</u>

The remainder of the ore deposits enumerated above for this horizon can be grouped into two classes, viz, those with a quartz or siliceous gangue and those with a siderite, dolomite or other related carbonate gangue for, as we shall see later, the barite did not arrive in the magmatic solutions but was already present in the repositories.

These two classes were clearly deposited from essentially different solutions but the absence of the intersection of one class by the other makes the determination of their relative age somewhat difficult. The fact, however, that the two classes occur at about the same level in any district, combined with the sporadic occurrence of fluorite and molybdenite in some of the siliceous class, seems to indicate that the solutions responsible for this latter class were the earlier. Accordingly this Siliceous-Lead-Zinc-Copper Stage is considered as immediately following the Tin-Tourmaline Stage.

The ore deposits assigned to this stage are the galena-quartz-pyrite lodes, the sphalerite-galena-pyrite-chalcopyrite-barite-quartz ore-bodies, the sphalerite-galena-quartz-chalcopyrite-tetrahedrite lodes, the pyrargyrite-barite ore-body, the chalcopyrite-quartz-pyrite lodes, the chalcopyrite-pyrite-barite-quartz-sericite ore-bodies and the bornite-barite-haematite deposit.

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(91) Davy W. Myron, Econ. Geol. Vol. XV 1920 p. 485.

It may seem strange at first sight that apparently distinct deposits such as the bornite ore-bodies at North Lyell on the one hand and the pyrite ore-body at Mt. Lyell and the zinc-lead-sulphide ore-bodies of Read-Rosebery on the other should be deposited during the one metallogenic stage. The significant facts which point to this genetic association are as follow:-

(i). The occurrence of quartz fissure veins springing from the walls of the pyritic ore-body at Mt. Lyell. These quartz veins carry pyrite and sphalerite and correspond to similar veins springing from the sphalerite-galena ore-bodies at Read-Rosebery, the composition in this case being quartz-sphalerite-galena-chalcopyrite and tetrahedrite. These veins are contemporaneous with the main sulphidic ore-body and show that the solutions depositing them both were essentially siliceous, the replacement within the ore-body being mainly by sulphides although in places quartz replacements occur.

(ii). The occurrence in the southern portion of the Mt. Lyell ore-body of bornite-chalcopyrite-quartz ore similar to that at North Lyell shows that the solutions were of the same general character for both.

(iii). The North Lyell ore-bodies contain galena in places.

(iv). Barite occurs associated with the rocks of the porphyroid complex as a result of the Epi-Cambro-Ordovician metallogenic epoch[92]. It is significant that no fissure-fillings carrying barite occur which are referable to the Epi-Silurian metallogenic epoch, but that in the ore-bodies of that age which contain barite it is an accompaniment of replacement. It is suggested therefore that the barite constituent of these ore-bodies, which never assumes more than a small proportion of the ore, has been derived from the rocks traversed and replaced by the siliceous lead-zinc-copper solutions. Some confirmation of this lies in the fact that barite common in the southern end of the Read-Rosebery zinc-lead-sulphide belt is relatively rare in exactly similar ore at the northern end.

(v). Finally it is noteworthy that the above-mentioned occurrences are the only Epi-Silurian ore deposits which carry barite at all. This would be inconceivable if the barium had a magmatic origin as it would certainly recur in some at least of the other metallogenic stages. This leaves the way open for the conception of a common siliceous solution.

The connection between the apparently dissimilar ore deposits of this Stage having been established there remains to be explained the general difference in mineralogic composition. Such explanation is based on regional variation within the magma, the predominant copper characterising the Lyell region while zinc and lead characterise the Read-Rosebery-Mt. Black region and lead the Dundas and Waratah-Heazlewood areas. There is very little evidence of zonal precipitation. A zinc zone lying below the main zinc-lead zone is suggested in the Hercules mine where the ore from the deepest bore shows very high zinc values. This, however, is to some extent discounted by the fact that such rich zinc ore occurs repeatedly in the upper levels. In the same mine a copper-rich ore-body is due to the influence of the

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92 Vide infra p.

rock replaced rather than the effect of a temperature zone.(93) It has been stated that the Mt.Lyell ore-body shows an increase in zone and lead with depth. This, however, was a misconception as the ore of that ore-body at its deepest point is exactly the same as near the surface. The sphalerite and galena contents are characteristic of the footwall portion of the ore-body rather than the deeper portion.

There now comes up for consideration a type of deposit the age of which has not yet been discussed herein. This type is the gold-quartz-pyrite lodes of Beaconsfield, Lefroy, Golconda, Mt.Victoria, Mangana and Mathinna constituting an irregularly shaped gold metallogeographic province of North-Eastern Tasmania. These lodes so closely resemble each other wherever they occur that a common genesis must be assigned to them.

Their occurrence outside the Blue Tier and Ben Lomond Cupolas and the repeated occurrence of granodiorite throughout the province indicate very clearly an origin from this granodiorite facies of the North-Eastern batholith. The general composition containing as they do quartz and pyrite, together with subordinate galena sphalerite and chalcopyrite, points to the possibility that they belong to this Siliceous-Zinc-Lead Copper Stage of the Inter-Cupola Trough Horizon. The free gold content which has made these lodes of economic importance and the relative paucity of the other mineral components represent a regional variation in the magma as between the North-Eastern and West Coast batholiths. It is important, however, to realise that both the North Lyell ore-bodies and the Read-Rosebery zinc-lead sulphide deposits carry ~~gold~~ free gold.

For these reasons, therefore, these gold lodes of North Eastern Tasmania are assigned to the Metallogenic Stage we are now considering and constitute a definite metallogenic province.

It is interesting to note that Malcolm Maclaren has contended that all of the gold deposits of Australia are genetically associated with granodiorite. The North-Eastern gold metallogenic province therefore owes its origin to the occurrence of granodiorite as a facies of the North-Eastern batholith whereas such a facies does not occur in connection with the West Coast batholith.

Carbonate-Lead-Zinc-Silver Stage.

The remainder of the ore deposits of the Inter-Cupola Trough Horizon were formed during this stage. In these lodes quartz is present in insignificant amount or is completely absent, the characteristic gangue being siderite, dolomite, ankerite or manganiferous siderite. The lodes herein included are as follow:- Galena-siderite-jamesonite-tetrahedrite lodes, tetrahedrite-siderite lodes, galena-dolomite-manganiferous siderite lodes, galena-pyrite-jamesonite lodes, sphalerite-galena-pyrite-siderite lodes, tetrahedrite-pyrite-chalcopyrite lodes, tetrahedrite-pyrite-galena lodes, and the arsenopyrite-siderite-pyrite lodes.

The localities in which the several types occur are given earliest in this chapter. It is noteworthy, however, that the pyritic type occurs in the western portion of the Zeehan field and in the centre of the Ringville area. The tetrahedrite is more pronounced in the Ringville area although common at Zeehan. Arsenopyrite is only developed in the extreme eastern portion of the Ringville area. The silver content of the lodes is general and is economically important and is carried mostly by the tetrahedrite and galena.

(93) Loftus Hills Geol.Surv.Tas. Bull 19 p.65.

Twelvetrees and Ward arrived at the conclusion that the pyritic type represented a deeper zone than the siderite types at Zeehan and stated their belief that a lode of the latter type when traced downwards would merge into a pyritic lode.[94] This conclusion was based on the assumption that the horizontal variation from Heemskirk eastwards is exactly repeated in a vertical direction. The influence of the conception of the cupola transfer and the two separate horizons resulting therefrom is to throw doubt on the justification for that assumption. There is some doubt therefore whether this transition from the sideritic to the pyritic type takes place in depth. The writer considers that the difference in mineralogic composition and the geographic distribution is due to regional variation within the magma rather than to zonal precipitation. The difference in the mineralogic composition merely takes the form of a variation in the relative amounts of pyrite, sphalerite and siderite, and solutions of the same general character were responsible for both types, but the variation in composition of such solutions in detail was due to the heterogeneity with the magma.

In any particular lode a zonal precipitation to a slight extent is observable particularly in the sideritic types which as followed downwards lose their galena contents and contain siderite only. This change to siderite in depth is mentioned by Beyschlag Vogt & Krusch as occurring in siderite-galena lodes and therefore this zonal precipitation at Zeehan is not unprecedented.[95] What change takes place in further depth at Zeehan is not known. Zonal precipitation is ~~also~~ in evidence in the Ringville district where tetrahedrite is highly developed in both the pyritic and sideritic types. These two types occur in two separate areas in the Ringville district, the former in the Ringville-Curtin-Davis area while the siderite type is developed to the east, south and west. This distribution is due to the variation in the magma but the great development of tetrahedrite is considered to be due to the surface in this district representing a cooler zone than the galena-siderite-pyrite zone and therefore overlying it.[95a] This corresponds to the principle enunciated by Spurr[96] that the antimonial silver minerals occur in a zone above the main galena zone. Similarly the arsenopyrite-siderite-pyrite lodes represent a cooler zone of this same series.

We have now to consider the galena-dolomite-manganiferous siderite lodes of Dundas, Magnet and Heazlewood which have not been included in the above discussion. These lodes, it is important to remember, are invariably associated with various basic rocks of the basic phase of the Epi-Silurian petrogenic period. It is of equal importance to note that the dolomite in these lodes has been introduced subsequently to the deposition of a normal siderite-galena lode, the latter having been irregularly fractured and the dolomite deposited in the locally more or less brecciated lode. This dolomisation extends a considerable distance beyond the lode into the surrounding basic rock which may be a pyroxenite, serpentine or websterite. By this dolomification the rock becomes a dense white dolomite.

The question arises therefore as to the mode of origin of this dolomite especially as to whether the calcium and magnesium contents were present in the magmatic solutions or

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[94] Twelvetrees W.H. & Ward L.K. Geol.Surv.Tas.Bull.8
[95] Beyschlag Vogt & Krusch "Ore Deposits" Vol.II p.653.
[96] Spurr J.E. Econ.Geol. Vol.XII p.489.
[95a] Vide Plate X which shows the outcrops of lodes at Ringville to be at a greater distance from the focus than those of Zeehan.

were derived from some other source. The writer unhesitatingly contends that a considerable proportion of these elements were not in the magmatic solution as it left its magmatic hearth but that the dolomite is the result of carbonated magmatic solutions reacting on the pyroxenites etc. Such dolomitisation of peridotites and pyroxenites has been considered very fully by Professor W.N.Benson(97) who shows that dolomitisation is a continuation of the process of serpentisation by the same magmatic solutions. He states:- "the carbonic acid at first acted as a catalyser, but subsequently under cooler conditions remained in combination with the magnesia."(98)

The dolomite in these lodes, therefore, has been formed as the result of the continuance of the emission of carbonated solutions after the siderite-galena lodes had been formed. These solutions were cooler than when the main lodes were formed and no longer carried the metallic components, representing in fact the final stage in the ejection of solutions from the inter-cupola troughs. The continuance of the carbonated solutions extended over such a period as to bring about not only the formation of dolomite in situ but the solution in the excess of carbonic acid of portion thus formed and its transfer to and subsequent deposition in fractures in the siderite-galena lodes and their environs. The occurrence of masses of dolomite associated with serpentines pyroxenites etc. is common on the West Coast of Tasmania, and the origin of this dolomite is ascribed to the ultimate effect of the carbonated solutions which converted the peridotites into serpentine. The dolomitisation being subsequent to the siderite-galena-deposition demonstrates that this action occurred late in the history of differentiation at the Inter-Cupola Trough Horizon.

When we turn to the Cupola Horizon, however, it becomes evident that dolomitisation occurred at a much earlier stage since we find that deposits of the Tin Stage have replaced dolomitised pyroxenite dykes. Dolomitisation was therefore complete at the Cupola Horizon before the ejection of the solutions responsible for the Tin Stage. In this case the dolomitisation must be due to the solutions of the Contact Stage, the carbonic acid component thereof being either an original constituent of the magmatic emanations or acquired thereby as the result of the metasomatic relacement of Carbonates during the formation of the contact-metamorphic deposits.

The above conclusions supply confirmation and some elaboration of Benson's summarised conclusion:- "the hydration was brought about by the agency of waters emanating from the same magma that produced the peridotite, though not generally until a considerable amount of further differentiation has taken place. The change was, however, completed by the end of the one orogenic period of vulcanicity."(99)

The completion of dolomitisation at the Inter-Cupola-Trough Horizon represents the end point of the Acid Phase of the Metallogenic Epoch and with it the end of the Epi-Silurian Metallogenic Epoch itself, as far as is indicated by ore deposits at present observable.

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(97) Benson W.N. "Origin of Serpentine" Am.Jour.Science Vol.XLVI pp.693-729.
(98) Ibid. p.710
(99) Loc.cit. p.727.

XIII. THE EPI-CAMBRO-ORDOVICIAN METALLOGENIC EPOCH.

A. PRELIMINARY SUMMARY OF THE CONSTITUENT ORE DEPOSITS.

In Chapter X a number of ore deposits have been definitely fixed as of Epi-Cambro-Ordovician age on the basis of direct geologic and mineralogic evidence. It now develves upon us to consider this Metallogenic Epoch in some detail and to investigaté from the genetic viewpoint certain ore deposits the origin or age of which have not so far been considered. First, however, let us enumerate those ore deposits the age of which has been determined as Epi-Cambro-Ordovician.

(i). Magnetite-chlorite ore-bodies of South Darwin, Lake Dora, Tyndal, Red Hills and Farrell districts.

(ii). Red Haematite ore-bodies of Jukes-Darwin, Lake Dora, Tyndal Red Hills and Farrell districts.

(iii). Chalcopyrite-chlorite-magnetite-pyrite ore-bodies of Darwin and the same districts as above.

(iv). Chalcopyrite-chlorite-haematite-pyrite ore-bodies in the same regions and at Dove River.

It will be seen that all of the ore deposits are confined to one well defined belt - the West Coast Range.

B. RELATIONSHIP TO THE METALLOGEOGRAPHIC PROVINCES.

It has already been pointed out that this Metallogenic Epoch was characterised by a preponderance of iron together with some copper. Accordingly it is not surprising to find that the Iron Metallogeographic Province of the West Coast Range includes within it this Iron Metallogenic Province. These two provinces - geographic and genetic - are however not identical in view of the existence within the former of haematite and specularite ore-bodies definitely fixed as of Epi-Silurian age and which will be considered from the genetic standpoint in a subsequent part of this work.

Similarly the Copper Metallogeographic Province of the West Coast Range contains both the Epi-Silurian and Epi-Cambro-Ordovician Metallogenic Provinces.

The concordance which exists between the geographic and genetic provinces for most of the Epi-Silurian genetic provinces, does not exist in the case of the Epi-Cambro-Ordovician, the West Coast Range being a region characterised by the superposition of two widely separated metallogenic epochs.

In the case of the Long Plains region, however, the iron deposits of which, as we shall see below, are probably of Epi-Cambro-Ordovician age, the geographic and genetic provinces coincide.

C. RELATIONSHIP TO THE PORPHYROID IGNEOUS COMPLEX.

(1). GENERAL RELATIONSHIP.

The determination of the exact role played in metallogenesis in Tasmania by the Porphyroid Igneous Complex has in the past been a very difficult matter. This difficulty arose through the confusion resulting from the development by dynamic metamorphism in purely effusive rocks of apparently holocrystalline characteristics. In Part I, however, special care has been taken to delineate the petrographic and structural characteristics of the members of this interesting igneous complex and to clearly indicate the origin of the various facies thereof by referring them to their position in the petrogenic cycle.

It has thus been shown, inter alia, that the truly intrusive and plutonic facies are relatively limited in their occurrence and are subordinate in amount to the effusive and schistose facies. The distribution of these plutonic, intrusive and extrusive types is shown in Plate VII wherein the acid and sub-acid facies are distinguished from the basic.

The ore deposits mentioned above as being of Epi-Cambro-Ordovician are also shown in the map and the spatial relationship obviously existing between them and the extrusive, intrusive and plutonic members of the Porphyroid Igneous Complex suggests a genetic association which we will now proceed to further investigate.

(2). RELATIONSHIP TO THE EXTRUSIVE PHASE.

Only a small number of ore deposits occur throughout the world which are regarded as having had their origin from within the extrusive facies of igneous rocks. It is generally recognised that such conditions for progressive differentiation as would occur only in considerable masses slowly cooling some distance below the surface, are essential to the formation of "magmatic extracts" which give rise to ore deposits.

It would be very unlikely therefore that we should find many ore deposits genetically associated with the effusive facies of the Porphyroid Igneous Complex numerous and extensive though they are. This is borne out by the observed occurrences which show very few ore deposits which would suggest such a genetic association with the exception of two types of deposits. These are the metallic copper deposit near Smithton on the North West Coast and the Red Haematite ore-bodies of the Jukes-Darwin field.

The metallic copper deposit near Smithton occurs in a basic member of the Porphyroid Complex which although now highly altered was originally a basalt. In this Basalt the copper occurs as blebs and scales of metallic copper. The deposit has not been worked and very little is known of it but the association suggests a mode of origin similar to that of the native copper deposits in basic lavas at Lake Superior etc. which constitute a type of ore deposit of world-wide distribution.

The Red Haematite deposits of Jukes-Darwin occur in the schistose facies of the Porphyroid Complex which, as demonstrated in Part I, represent metamorphosed volcanic tuffs. These ore-bodies are distinctly different from the micaceous haematite and magnetite deposits of the same region consisting of dense massive red haematite with no pyrite whatsoever. Their distribution is sporadic and they are apparently not immediately adjacent to the intrusive and plutonic facies of the Complex. As their age is definitely fixed as Epi-Cambro-Ordovician by the finding of pebbles composed of this material in the West Coast Range Conglomerate Series, three possible explanations as to their origin suggest themselves. One such explanation would regard the deposition of iron to have taken place as carbonate or oxide concurrently with the original submarine accumulation of the volcanic ash. Subsequent metamorphism has converted the oxide or carbonate to this dense haematite. The source of the original iron would be ascribed to the intense vulcanicity and ejection of volcanic rocks belonging to a petrogenic period which was characterised essentially by the presence of large amounts of iron. Against this mode of origin may be cited the fact that the haematite shows no marked schistosity which would be expected to be developed simultaneously with that of the rock repository. The only occurrence of schistosity within the haematite is an area of intense Epi-Silurian crushing and has obviously been developed at that period and not simultaneously with the schistosity of the schists.

The second possible explanation is that they are the result of the solution and migration, through the agency of the vadose circulation, of the haematite and magnetite bearing deposits to be subsequently ascribed to the plutonic phase of the Porphyroid petrogenic period. This solution and migration would have taken place in the period succeeding the batholithic end-point and during the progress of the erosion which laid bare the plutonic rocks and their genetically related ore deposits.

The third explanation of the origin of these red haematite ore-bodies which is the one put forward by the writer as the most probable is that they represent the replacement of schist by solutions rich in iron emitted from the differentiating plutonics during the Iron Stage and deposited at greater distances from the magmatic hearth than the magnetite and micaceous haematite. This will be further considered below when dealing with the Acid Phase.

3. RELATIONSHIP TO THE BASIC PLUTONIC PHASE.

In a metallogenic epoch characterised by dominant iron as is this Epi-Cambro-Ordovician Metallogenic Epoch of Tasmania, it would naturally be expected that the basic plutonic phase of the coordinate petrogenic period would be particularly rich in important concentrations of iron ore. This expectation is realised in that the only representatives of the basic plutonic rocks of the Porphyroid Igneous Complex known to exist, viz., the amphibolite-schists and gabbro-amplibolites of the Long Plains and Rocky Ricer districts, carry large lenses of magnetite which constitute some of the most important iron deposits of Tasmania.

The amphibolite-schists and gabbro-amphibolites in which these ore deposits occur were originally, as established in Part I, gabbros and related rocks. These were intruded into Pre-Cambrian schists of sedimentary origin.

The magnetite ore-bodies occur in the hornblende-schists in the form of lenses up to 2000 feet in length and 100 feet in width. They are conformible to the schists and in places a banding appears corresponding to that in the schists or hornblende-gneiss as the rock in places may be called. The ore is mainly magnetite with some haematite, the gangue being small in amount and consisting of hornblendic material and in places the sulphides pyrrhotite, pyrite and chalcopyrite occur together with a small amount of nickel and cobalt.

In determining the genesis of these deposits it must be remembered that we we are dealing here with basic igneous rocks which have been subjected to intense dynamic metamorphism which has brought about mineralogic reconstitution and the development of the schistose and banded structure. Magnetite ore-bodies occurring in these rocks and possessing a banded structure could be metasomatic replacements by solutions arriving subsequent to the development of schistosity as perhaps the Epi-Silurian magmatic solutions. The absence of the typical gangue minerals such as garnet, idocrase, diopside, etc., render this mode of origin doubtful. When, moreover, the magnetite is accompanied by nickel and cobalt as in these ore-bodies it seems still more doubtful that metasomatic replacement is responsible for them. It would appear therefore that magmatic differentiation has been the process which has developed the magnetite with the pyrrhotite, chalcopyrite, nickel and cobalt which are so characteristic of magmatic differentiates of this type.

On the basis of the origin by magmatic segregation of these deposits their age would be that of the original gabbro intrusion, namely, Epi-Cambro-Ordovician. The banding and lenticular shape are the result of the same forces and processes as developed the banding and schistosity in the igneous host.

A difficulty in the acceptance of the origin by magmatic segregation arises by virtue of the fact that the ore-bodies carry no titanium. Magmatic segregations in gabbros are in general characterised by the presence of this latter metal in the form of ilmenite. This, however, is not invariably the case as is shown in Tasmania by the magnetite-pyrrhotite-pentlandite segregations in gabbro at Heemskirk and beyond Tasmania by the occurrence of non-titaniferous magnetite ore-bodies in gabbros in Brazil.

On the evidence, therefore, the origin is believed by the writer to have been by magmatic segregation within and towards the borders of intrusions of rocks approaching gabbro in composition and belonging to the basic phase of the porphyroid igneous complex, and they are therefore of Epi-Cambro-Ordovician age.

These magnetite deposits of the Long Plains and Savage River represent the only ore deposits genetically associated with the basic plutonic phase of the Porphyroid Igneous Complex.

4. RELATIONSHIP TO THE ACID-PLUTONIC PHASE.

In the early part of this chapter it was pointed out that the association of the ore deposits, definited fixed as of Epi-Cambro-Ordovician age on purely geologic evidence, with the plutonic facies of the Porphyroid Complex suggested a genetic connection. Plate VII shows that such a genetic relationship would be with the acid and sub-acid facies - a conclusion which is really indicated above where it is stated that the Long Plains and Savage River magnetite ore-bodies are the only genetic associates of the basic phase of the Complex.

Iron Stage.

The acid and sub-acid plutonics occur as outcrops at either end of the West Coast Range - at South Darwin and at Farrell. The tectonic geology and the history of the Porphyroid petrogenic period as delineated in Part I show that similar plutonic invasions are probable along the whole of this mountain range.

The ore deposits containing magnetite and haematite which are referred to this epoch are distributed along the same range and we find a recurrence of a typical deposit of this class coinciding with the recurrence of porphyroid granite at Dove River.

It seems very clear therefore that these deposits are genetically related to the acid and sub-acid plutonics. This conclusion shows the existence of a parallel in the Epi-Cambro-Ordovician Metallogenic Epoch to the Contact Stage of the Acid Phase of the Epi-Silurian Metallogenic Epoch. It is important to note, however, that the usual lime-silicate contact metamorphic minerals garnet, etc. are absent, chlorite being the characteristic silicate. It is equally noteworthy that the ore deposits are not confined to the juxtaposed aureole but occur also within the plutonic masses themselves. It would seem therefore that these iron deposits do not belong to a definite Contact Stage as ordinarily understood, but that they represent the earliest stage of ejection of magmatic ~~cont~~ ract which took place at a somewhat later stage of the intrusion-cooling-differentiation history than the typical contact-metamorphic stage. It is therefore called the Iron Stage.

The ore deposits belonging to this Iron Stage are the magnetite-chlorite micaceous haematite-quartz-pyrite and the red haematite ore-bodies of the West Coast Range and Dove River together with the chalcopyrite-chlorite-magnetite-pyrite and the chalcopyrite-chlorite-haematite-pyrite ore-bodies of the same regions. These latter deposits carrying copper (about ·5 per cent average) are variants of the magnetite-chlorite ore-bodies and actually are of more frequent occurrence than the purer type. The chalcopyrite was the last mineral to be deposited but there was possibly some overlapping with the iron minerals. It is apparent therefore that some copper accompanied the later solutions of the Iron Stage. In places, however, the solutions carried iron only with no sulphidic or copper content and gave rise to the red haematite ore-bodies.

An interesting variant of these iron deposits with subordinate copper are the bornite - bluish grey haematite lodes at Lake Jukes. These are assigned to the Iron Stage the deposition of the bornite having been determined by the physical conditions to which the solutions were subjected at this particular locality. They are regarded by the writer as corresponding to the red haematite deposits having been deposited under approximately similar conditions from copper-bearing solutions.

Copper Stage.

It has been shown above that the Iron Stage included towards its close a noticeable copper content. This leads to the problem of the age and genesis of the chalcopyrite-chlorite-pyrite ore-bodies which occur along the West Coast Range in close proximity to the above mentioned magnetite and haematite deposits. These ore-bodies are confined to the schistose facies of the Porphyroid Igneous Complex while the cupriferous magnetite and haematite deposits occur in the more massive rocks such as felsite granophyre or granite. Although these two distinct types occur in close proximity to each other they invariably constitute quite separate ore-bodies.

The characteristic component of these ore bodies is chlorite which is generally in the form of delessite. Gold and silver are present in the chalcopyrite to a small extent. The invariability of the chlorite give a distinctive appearance to these ore bodies and they undoubtedly constitute a genetic group. We have seen, however, that certain copper deposits of the West Coast Range belong to the Epi-Silurian Metallogenic Epoch and it is of course possible that these chloritic chalcopyrite deposits belong to that epoch especially as up to the present no fragments of these ore-bodies have been found in the West Coast Range Conglomerate as is the case with the magnetite and haematite deposits. It is significant, however, that the Epi-Silurian copper deposits on this range occur at Mt. Lyell where the disseminated deposits in the schists (fahlbands) are characterised by sericite and not chlorite. In fact there is complete evidence in the Lyell field that the sericite of the sericitic schists adjoining the main ore-bodies has been produced by the action of the Epi-Silurian ore-bearing solutions on chloritic schists. This is in accordance with Kirk's (100) conclusion that chloritisation and sericitisation are the resultant products of different phases of hydro-thermal action, although the completion of the conversion of Epi-Cambro-Ordovician chlorite to sericite has in this case been delayed until the arrival of solutions at a much later geologic period.

It seems very probable therefore that the chloritic ore-bodies belong to the Epi-Cambro-Ordovician Metallogenic Epoch in view of their juxtaposition to Epi-Cambro-Ordovician plutonic invasions and also because of the occurrence of sericite and not chlorite in the ore-bodies definitely known to be of Epi-Silurian age. The evidence is not conclusive but these chloritic ore deposits present an appearance in the field so different from any Epi-Silurian deposits that one can scarcely believe them to belong to the latter epoch. It may be objected that because the ore-bodies are metasomatic replacements of schistose facies of the Porphyroid Complex the schist structure being retained in the ore, an Epi-Cambro-Ordovician age could not be assigned to them as the schistosity is also of Epi-Cambro-Ordovician age. It was specially shown in Part I, however, that the metamorphism of the schistose facies was effected before at least the completion of the plutonic or batholithic phase of the Epi-Cambro-Ordovician orogenic epoch. The ejection of magmatic solutions being the later stage of the batholithic invasion, such solutions would find the schists with their schistosity already developed awaiting them and would afford both easy channels of movement and favourable material for replacement. They are therefore regarded by the writer as belonging to the Epi-Cambro-Ordovician Metallogenic Epoch.

This conclusion in view of the complete absence of magnetite and haematite in the ore-bodies gives rise to the conception of a second stage of the epoch characterised by copper and no iron. It is therefore termed the Copper Stage.

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(100) Kirk Charles T. Econ. Geol. Vol. VII p. 35-52.

Its separation from the Iron Stage in the matter of time was due to the operation of the same principles as were enunciated in connection with the Stages of the Epi-Silurian Metallogenic Epoch.

There is no evidence whatsoever of any subsequent stage of this epoch and it therefore is clear that the Epi-Cambro-Ordovician Metallogenic Epoch was essentially one giving iron and copper with a little gold and silver and that of these ~~two~~ metals iron was by far the most important. This conclusion is made more significant when the deposits of the Basic Phase of this epoch are remembered as they were dominantly iron with a little nickel and cobalt.

The Epi-Cambro-Ordovician was therefore par excellence the Iron Metallogenic Epoch of Tasmania.

XIV. ORE DEPOSITS FORMED DURING ANAMORPHISM.

We have now considered all of the ore deposits of Tasmania important from either the economic or genetic view-point with the exception of the bluish-grey haematite-quartz ore-bodies, the haematite-barite ore-body of Mt.Lyell, the specularite-quartz veins and the barite lodes. A direct origin from igneous magmas has been ascribed and demonstrated for them all but the exceptions mentioned above do not seem to have such a direct association and their mode of origin now comes up for consideration.

(1). HAEMATITE DEPOSITS IN WEST COAST RANGE CONGLOMERATE.

The significant facts in connection with the bluish-grey haematite-quartz ore-bodies, the specularite-quartz veins and the baritic haematite deposits are the following:-

(i). Their occurrence as metasomatic replacements ~~of~~ & veins in conglomerates and sandstones of the West Coast Range Conglomerate series.

(ii). The complete absence of magnetite.

(iii). The total absence of pneumatolytic and hydatogenic minerals; quartz and barite are the only gangue minerals.

(iv). Their occurrence immediately above or in contact with members of the Porphyroid Igneous Complex.

(v). The occurrence of conglomerate beds rich in magnetite and haematite pebbles and haematite cement within the Conglomerate Series.

The age of these deposits has been definitely fixed as Epi-Silurian on the ground that they occur in the Silurian West Coast Range Conglomerate Series and that Epi-Silurian magmatic ore deposits (the Mt.Lyell and North Lyell ore-bodies) occur partly replacing them. More exact determination of age is therefore possible and it is thus clear that their formation pre-dated the Siliceous-Lead-Zinc-Copper Stage of the Acid Phase of that epoch.

If therefore these deposits were due to magmatic solutions they would necessarily have to be referred to the earlier Contact Stage (if such exists for the Inter-Cupola Trough Horizon) or to the Tin-Tourmaline Stage. The absence of any magnetite, pneumatolytic or similar minerals, however, makes such an origin very improbable.

In view of the definite age determination there remains one mode of origin which explains the occurrence of these deposits, viz., an origin during the orogenic movement and preceding the batholithic end-point. The vadose water has its temperature and activity increased by the pressure accompanying the paroxysm, and dissolves iron and silica from the surrounding rocks and Epi-Cambro-Ordovician iron ore-bodies and deposits them wherever decreased temperature and pressure are encountered.

Such solution transfer and deposition of iron and silica have taken place to a considerable extent within the West Coast Range Conglomerate especially where the crushing and movement during the Epi-Silurian orogenic period was intense. Very interesting illustrations of this on a small scale are frequent in the conglomerate beds carrying haematite pebbles. In one type a quartz vein cuts through a haematite pebble and within the borders of this pebble specularite occurs ~~with~~ in the vein in addition to quartz, whereas the remainder of the vein consists wholly of the latter mineral. Obviously in such veins there has been practically no movement of the solutions, a conclusion which is confirmed by the occurrence of the quartz in columnar growths extending completely across the vein. Another type of vein is frequent which carries well crystallised pyramidal quartz with specularite. The rock in the near neighbourhood contains numerous pebbles of haematite and much haematite cement. There has clearly been free movement within veins of this type.

On a much larger scale deposition of haematite has taken place by metasomatic replacement of sandstones which were permeated by the iron-bearing solutions circulating during the differential movement of the rock masses. To this type belong the more important haematite ore bodies in the Conglomerate Series exemplified by those at Blythe, Dial Range and similar but much smaller deposits on Mts.Lyell,Owen and Claude.

The barite-haematite ore-body at Mt.Lyell is a variant of this type the circulating waters having picked up a narium content from the same source as the later magmatic solutions which gave rise to the Mt.Lyell pyritic ore-body.

The writer would ascribe the origin of all of these haematite and specularite deposits to this solution transfer and deposition during the phase of the Epi-Silurian orogenic period preceding the batholithic invasion.

(2). BARITE VEINS IN PORPHYROID IGNEOUS COMPLEX.

Veins of barite are not infrequent in the effusive and intrusive igneous rocks of the porphyroid complex and include the following types indicated in Table :- The barite-pyrite-quartz lodes of the Jukes-Darwin (Intercolonial Spur), Hamilton on Forth (Alma) and Farrell (Kittsons etc). These lodes contain predominant barite with ~~with~~ subordinate chalcopyrite, pyrite and quartz together with sphalerite and galena and sometimes barite in a very pure state.

It is significant that these veins are confined to the Cambro-Ordovician igneous rocks and contain predominant barite with occasionally a little pyrite, chalcopyrite or galena. They can in no way be regarded as of the baritic-galena type of lode at Freeberg being essentially veins of barite with a slight impurity of the three minerals mentioned above. The barite is generally white but occasionally stained with haematite.

Very little work has been carried out on these veins but in the one case where a vein has been explored at appreciable depth (Intercolonial Spur between Jukes and Darwin) it shows a feathering out downwards. It is widest nearest the surface and peters out below to thin veinlets.

Taking cognisance of these facts the writer would ascribe the origin of these barite veins to the action of meteoric waters in the deeper circulation acquiring barium from the silicates of the igneous rocks in which they occur and depositing it as sulphate in open fissures. This is in accordance with the mode of origin deduced for many barite veins in other parts of the world . It does not seem possible to account for them in any other way in view of their recurrence over a wide area and the absence of barite from all of the deposits formed from magmatic solutions except the two isolated instances of the Mt. Lyell ore bodies and the Read-Rosebery zinc-lead-sulphide deposits, the barite in which is explained above as having been picked up by the magmatic solutions in passing through the Porphyroid Igneous Complex. If barium had been present in the magmatic solutions of either of the main metallogenic epochs it would of necessity have shown its presence in some at least of the other types of deposits belonging thereto, particularly in the lower temperature groups.

As to the time of depositiom of these barite veins no final conclusion is at present possible. It is quite possible that they were formed during the erosion interval between the Cambro-Ordovician orogenic period and the Silurian sedimentation and their restriction to the Cambro-Ordovician rocks would lend support to this view. The fact, moreover, that barite occurs in the two Epi-Silurian ore deposits, seems to indicate that that mineral was ready in places in available form to ~~ihs~~ be taken up en passant by the magmatic solutions. These considerations point to a Pre-Silurian and Post-Cambro-Ordovician origin and this is considered by the writer as probable. However, it is possible that they may have been deposited at the same time and under approximately the same conditions as the haematite and barite-haematite deposits in the West Coast Range Conglomerate and this seems to be confirmed by the occurrence at an isolated spot at North Lyell of small barite replacements of conglomerate.

In all probability, therefore, solution and redeposition of barium has taken place during both the Epi-Cambro-Ordovician-Silurian erosion interval and the earlier part of the Epi-Silurian orogenic period. Further data are therefore essential before the exact age of the individual occurrences of barite veins can be determined.

XV. SECONDARY ALTERATION OF THE ORE DEPOSITS.

In general the amount of secondary alteration of the ore deposits of Tasmania by atmospheric agencies and meteoric waters is very small. This fact is explained by the heavy rainfall well distributed throughout the year and the absence of dry seasons and the rapid erosion in the mineral areas of the West and North-West Coasts and Ben Lomond. Thus in spite of the high relief the conditions necessary for extensive development of oxidation and secondary enrichment do not exist in these areas.

The secondary alteration generally consists of a very shallow zone of oxidised lode material or gossan which seldom extends to more than 100 feet below the surface. Very little secondary enrichment has occurred, a notable exception being the copper-silver-gold enrichment containing argentite, bornite, chalcocite and polybasite on the footwall of the Mt.Lyell ore body. Another important case of extensive surface alteration is that of the Mt.Bischoff ore-bodies but in this instance the result is not due solely to Tertiary, Pleistocene and Recent effects. As pointed out in Part I, Mt.Bischoff was a monadnock when the Pre-Permo-Carboniferous peneplain was formed. The erosion interval which gave rise to this peneplain undoubtedly was responsible for the development of a considerable portion of the oxidation and enrichment of the tin lodes. The extent and richness of these oxidised deposits of Mt.Bischoff is therefore due to the superposition of a succession of erosion periods on a persistent monadnock.

The free gold found in numerous localities in the West Coast region in alluvial and detrital deposits has been formed during the oxidation and alteration of the various pyritic ore-bodies which contain gold associated with the sulphides and removed during the ordinary progress of denudation.

On the East Coast where the rainfall is considerably less than in the West and a relatively long dry summer occurs every year secondary alteration extends to a greater depth but even here it does not seem to extend to more than 100 feet.

The erosion which has taken place since the early Tertiary has liberated enormous quantities of cassiterite from ore deposits containing that mineral. This cassiterite has become concentrated in river gravels forming extensive alluvial deposits. Some of these deposits of Tertiary age have been covered by Tertiary basalt and constitute the"deep leads" of North-East Tasmania which is also the area which contains the more important and extensive alluvial tin deposits of Tasmania.

On the whole therefore secondary alteration and enrichment have not affected the ore deposits of Tasmania to an extent comparable to that on the mainland or in many other parts of the world, the main mineral output of Tasmania with the exception of the Mt.Bischoff deposits and the tin placers of the North East Coast being derived from primary ore deposits.

DESCRIPTIONS OF PLATES.

PLATE I.

This is the official geological map of Tasmania with the West Coast Range Conglomerate Series added as a separate rock series. Several alterations have been made where observations subsequent to the printing of the official map showed that it was inaccurate. This map is also intended to act as a general locality map. The lines of sections in Plates IV and V are marked on this map.

PLATE II.

This map indicates in a generally approximate way the position of the main Late Mesozoic and Tertiary fault lines of Tasmania. The faults which have been caused by the diabasic upthrust are coloured pink while the lines of Tertiary block faulting are shown in yellow. The amount of throw in each case is shown in feet.

PLATE III.

The occurrence of the granite of the Porphyroid Complex at South Darwin is here shown in plan and in vertical cross section. The former shows the truncation of both the bedding planes and the schist planes by the granite. The section shows the roof-pendant with the schist planes clearly truncated vertically by the granite.

PLATE IV.

The upper of the two sections in this plate is a vertical section on a line from Heemskirk through Comstock, Zeehan, Dundas, Mt.Read, Farrell, Granite Tor, Barn Bluff, Cradle Mt., Middlesex, Beaconsfield, Lefroy, Warrentinna, Blue Tier to the East Coast. The geologic units shown thereon are the acid and sub-acid plutonics of the Epi-Silurian shown in red, the Silurian and Pre-Silurian rocks shown in purple and the Permo-Carboniferous and post-Permo-Carboniferous in sepia. The position of the planes of the block faults is also shown.

The lower section is along the same line and has been evolved from the upper by raising the faulted blocks by as much as they originally dropped - 3000 feet on the West Coast and from 3000 to 2000 feet going eastwards along the North Coast. The raising of these blocks to their original position shows the Tasmanian Batholith in its true outline and relationships. In this section are thus shown the original configuration of the batholithic roof on the line of the section, the denuded portion of the cupolas being shown by broken red lines. The surface at the time when the igneous invasion reached its maximum height is shown in a broken black line which shows in general the undulations of the surface which were the effect of the orogenic movement. The Permo-Carboniferous peneplain is shown by a thick continuous black line, the monadnocks being shown slightly higher than present level to indicate diagrammatically erosion which has since taken place.

The West Coast batholith and that of the North-East are shown joining at a considerable depth below the surface and thus the conception of the Tasmanian Batholith is illustrated.

PLATE V.

These sections are designed on exactly the same lines as those in Plate IV, the section line being from the Coast south-west of Balfour through the Norfolk (Balfour) Range, the Meredith Range, Mt.Merton and Granite Tor to Mts.Pelion and Doris. Two cupolas are shown which do not outcrop at the surface, viz, the Mt.Merton and Pelion Cupolas.

These sections show the underground continuity of the batholith across the "north-east, south-west weak zones" of Ward - a continuity which the latter contended did not exist.

PLATE VI.

The base map of this plate is merely a skeleton map of Tasmania. On it are shown the Metallogeographic Provinces, each metal being indicated by a characteristic colour shown in the legend.

PLATE VII.

The same skeleton map as in Plate VI is used for this plan. On the base map are plotted in outline by broken lines the metallogeographic provinces which, however, are not coloured.

The Epi-Silurian plutonic outcrops are shown in carmine the acid, sub-acid and basic facies being shown as distinct. The outlines of the base of the Cupolas are shown as continuous thick block lines.

The hypothetical outlines of the two batholiths are shown in ~~as~~ red ~~circles which must~~.

The plutonic members of the Porphyroid Igneous Complex are shown in vermilion the basic being shown distinct from the acid. Similarly the effusive and intrusive members of the same Complex are shown.

The tectonic lines are shown for the three diastrophic periods in separate colours. These are shown as continuous lines where ~~the~~ directly observable and as broken lines where their presence or continuation is inferred.

Diabase and basalt are not shown.

PLATE VIII.

On this plan are shown the more important fissure lodes of the Heemskirk, Zeehan, Dundas, Renison Bell, Farrell and Stanley River areas. The lodes of the various metallogenic stages are indicated by characteristic colours. In some cases the lengths of the lodes have been slightly exaggerated.

The tectonic lines are shown by characteristic colours being projected on to the area from the nearest point if no data are available in the area covered by the map.

The map also shows the Epi-Silurian intrusives too small for the general geological map, the acid being shown distinct from the basic.

PLATE IX.

This is designed on exactly the same principle as Plate VIII and covers the Balfour region. The granite is not shown but the amphibolite dykes are indicated, they being too small to show on the general geologic map.

PLATE X.

The object of this plate is to show the relation of the lodes and metallogenic stages to the Cupolas and Inter-Cupola Troughs.

There is shown very largely diagrammatically a vertical section across Heemskirk through Comstock, Zeehan, North Dundas to east of Ringville. Only the acid Epi-Silurian rocks are shown. There are thus illustrated two Cupolas and two Inter-Cupola Troughs. The original outline of the truncated cupola is shown by a broken red line, and the original surface at the time of the batholithic invasion by a broken black line.

The contact-metamorphic iron deposits are shown in black.

The Tin and Zinc-Lead-Copper Stages of the Cupola Horizon are shown respectively as purple and brown lodes issuing from the granite, the greater depth, below the batholithic roof, of the latter indicating their origin at both a later stage and a deeper focus.

Similarly the three Stages of the Inter-Cupola Trough Horizon are indicated by characteristic colours and the progressive increase in depth of focal origin indicated. In this case the pyritic-galena are shown distinct (yellow) from the sideritic-galena (blue) lodes although they both belong to the Carbonate-Lead-Zinc-Silver Stage. The result of this procedure is to clearly show the dependence of the mineralogic composition of these two lode types on variation within the magma.

The drawing also shows why the lodes in the Ringville area belong to the cooler zone carrying tetrahedrite than those at Zeehan, being at a much greater distance from the intra-magmatic focus. In every case the lodes or portions thereof which have been removed by denudation are shown as broken lines.